TURBINE PASSAGE SURVIVAL PROGRAM
FY97 ANNUAL REPORT

EXECUTIVE SUMMARY

The Turbine Passage Survival Program (TSP) was developed to investigate means to improve the survival of juvenile salmon as they pass through Kaplan turbines located at Columbia and Snake River dams. The TSP is one part of the U.S. Army Corps of Engineers (COE) multi-faceted Columbia River Fish Mitigation Program. The purpose of this annual report is to document the studies and findings that were conducted under the TSP in FY97. Funding and regional support for the TSP was provided in April 1997. Thus, work was initiated on the program about halfway through FY97. Technical staff from the COE Portland and Walla Walla Districts, Waterways Experiment Station (WES) and Hydroelectric Design Center (HDC) are team members on the TSP.

The Project Study Plan (PSP) for the TSP was approved in August 1997. The PSP describes the original scope and schedule for the program. The TSP was scheduled as a three-year program. It was to be initiated in October 1996 and completed by September 1999. The September 1999 completion date was selected so that information from the TSP could be incorporated into the 1999 recommendation for the future operation of the Lower Snake River reservoirs currently being evaluated in the Lower Snake River Feasibility Study. In this way information from the TSP on potential improvements to fish survival through operational or design changes to Kaplan turbines could be factored into the recommendation process and environmental documentation for the Lower Snake River Feasibility Study.

The objectives of the TSP are: (1) Develop modifications to the way existing Kaplan turbines are currently operated to improve fish passage survivability and condition as they pass through the existing turbines, (2) Identify biological design criteria that will provide the basis for the development of improved turbine designs,   (3) Investigate improved fish passage turbine designs or modifications to existing designs that could be implemented to assist the recovery of Columbia and Snake River salmon stocks, and (4) Provide information on turbine passage survival, which can be factored into the 1999 system configuration decisions.

The TSP is organized along three functional elements and disciplines that must be investigated and integrated to achieve the objectives of the program. These are biological, engineering, and hydraulic model investigations.

- In FY97, work on the biological studies element of the TSP focused on planning, purchasing equipment, and developing study designs for the biological evaluations that will be conducted.   A biological study design for a balloon tag evaluation of the newly rehabilitated units at Bonneville First Powerhouse was developed. Similarly, a study design was also developed to evaluate differences in fish survival, condition, and injury between areas of the new "minimum gap" runner (MGR) being installed at Bonneville First Powerhouse, through the rehabilitation

program. Areas of focus are the blade tip gap, hub gap, and mid-blade areas of passage for fish. Similarly, a study design was developed in FY97 to identify the areas and mechanisms of injury that might be occurring in Kaplan turbines in general. A turbine at McNary Dam has been selected for testing this objective of the TSP. Release points for the evaluation will be based on results of hydraulic model studies of the McNary turbine passage route. In-turbine fish trajectory-mapping methodologies were investigated in FY97. A review was conducted of various sensing methodologies that could be used to locate and track fish as they pass through a turbine intake.   Ultrasonic tracking was selected as the best methodology to verify that fish trajectories match the trajectories predicted by the hydraulic model. Design of the ultrasonic tracking system was completed and procurement was initiated.

- In FY97, engineering studies focused on preparations for turbine efficiency optimization studies, and engineering support to the hydraulic model studies of the McNary turbine passage route and biological evaluation studies at Bonneville and McNary dams. Procurement of field testing equipment required for turbine efficiency optimization and support of the biological evaluations was initiated. This included the design and contract award of a scintillation flow measurement system to more accurately measure turbine discharge and turbine intake velocity profiles. In FY97, work was initiated on the development of "on cam" relationships for McNary and Bonneville First Powerhouse, through derivation from multiple sources of information. Engineering activities in FY97 supported the within-turbine fish distribution imaging effort. The potential use of computational fluid dynamics to assist the TSP was also investigated.

- Hydraulic model investigations were initiated in FY97 at the COE's WES. Flow characteristics and distribution through low head physical models of McNary and Bonneville 1st Powerhouse were initially investigated . Existing three bay, single unit 1:25 scale sectional models were used.   The FY97 effort focused on turbine flow distribution measurements and developing visualization techniques. Neutrally buoyant beads were used to represent fish passage and determine potential hazards to fish. Dye tracings were used to verify flow distribution lines. High-speed video and digital photography techniques were explored to provide stop action representation of neutrally buoyant bead behavior and distribution.   Based on these studies, the turbine passage environment was divided into eight zones for further study. These include the intake entrance to the intake gate slot, intake gate slot through the start of the scroll case, scroll case, stay vanes and wicket gate area, turbine runner and hub, draft tube expansion and elbow to pier nose, draft tube pier nose to exit, and the draft tube exit to the tailrace. Water flow from the intake gate slot through the wicket gates was characterized. Some preliminary water flow information was also obtained for the remaining areas. Results indicate that fish passage routes through a unit are very sensitive to release point location in the intake.

Work that is related to the TSP and conducted by other groups includes the Department of Energy's (DOE) Shear Program, the Turbine Working Group (TWG), the Electric Power Research Institute's (EPRI) pressure studies, operation beyond the current 1% efficiency limit, Lower Granite drawdown and surface bypass turbine studies, and McNary extended bar screen performance testing. Results from these activities are reported. In addition, future year activities under the TSP are described. These include biological and engineering studies and hydraulic model investigations .

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

Under present conditions, direct fish survival through Columbia and Snake River turbines ranges from approximately 89-94%. The primary focus of this study is to gather information that will allow an accurate evaluation of fish passage benefits associated with turbine operational changes and changes resulting from the incorporation of improved fish passage turbine design concepts. Information gained from this study, therefore, may be incorporated into existing turbine systems in two ways: through operational changes and/or future turbine rehabilitation programs.

In response to the Northwest Power Planning Council's (NPPC) request to enhance the survival of migrating adult and juvenile salmonids passing the Columbia and Snake River projects, as well as the National Marine Fisheries Service (NMFS) 1995 Biological Opinion for system operations as Conservation Measure No. 5 (develop a program to study/improve fish passage through turbines), Reasonable and Prudent Alternative No. 6 (operation of turbines within 1 percent peak efficiency) and Reasonable and Prudent Alternative No. 15 (improving fish passage with a goal of 95 percent survival through each project), studies for various improvements to these projects were undertaken. In 1994, the COE completed the System Configuration Study (SCS) to investigate various improvements to the Columbia and Snake River hydrosystems. The two major items corresponding to turbine passage survival resulting from the SCS were the Turbine Passage Survival Workshop and the Turbine Basecase Report.

The Turbine Passage Survival Workshop was held in Portland, Oregon on May 31-June 1, 1995. The workshop was comprised of a 20-member panel of engineering and biological experts from government, industry and universities, along with over 50 non-panel participants. The major goals of this workshop were to: (1) Determine how to deliver fish from the turbine to the tailrace environment that are ready to cope with the river environment, (2) Focus on those uncertainties that prevent closure on developing biological turbine design criteria, and (3) Identify and prioritize the causal agents of turbine mortality. The general conclusion from the workshop was that there are physical and operational modifications to the turbines that have already been identified that could possibly increase the survival of fish passing through the turbine environment.

The Base Case report, entitled "Turbine Passage Survival Baseline Turbine Report", was completed on January 19, 1996. The purpose of the base case report was to gather data on physical attributes of turbines and the ability to perform prototype tests for eight prospective base case sites. Data from the report were used to select a site to perform engineering and biological prototype tests to be conducted under the TSP. A number of factors were evaluated in determining which site would be selected, including powerhouse capacity and the ability to use the selected unit without largely interfering with

hydrosystem operations. McNary Unit 5 was selected by the COE as the base case prototype test site. This decision was made in coordination with regional fishery agencies, tribes, and the Bonneville Power Administration (BPA).

1.2 TURBINE PASSAGE SURVIVAL PROGRAM

 The TSP has been organized along two time frames, short term (Phase I) and long term (Phase II). The goal of Phase I is to explore methodologies for evaluating and understanding fishery impacts caused by turbine operation, develop turbine operational changes to improve fish passage through turbines, identify biological criteria for use in turbine re-design, and develop recommendations for future turbine studies. Phase II will implement the recommendations described in the TSP Phase I Final Report. Two options for Phase II implementation will be considered. The first option consists of conducting prototype tests on a modified turbine at the base case site, McNary Dam. The second option consists of incorporating results directly into an ongoing rehabilitation program.

To develop biological turbine design criteria, operational and physical modifications, and to provide a study of cost effective alternatives, Phase I of the TSP has been divided into three distinct yet integrated tasks: biological studies, engineering studies and hydraulic modeling. This report, the first annual report of the TSP, presents a summary of efforts and results achieved in FY97 on each of the tasks, as well as a discussion of activities planned for FY98 and activities related to the turbine program. This report will be combined, along with additional annual reports and task reports written at the conclusion of the study by each of the tasks, into a final report that will focus on stating what was tested, why, results, recommended operational and design modifications and recommendations for Phase II.

SECTION 2

PHASE I PROJECT STUDY PLAN

2.1 PROGRAM PHILOSOPHY

The region is currently evaluating a wide range of significantly different strategies for restoring the anadromous fish runs on the Snake and Columbia Rivers to acceptable levels. Portland and Walla Walla Districts have developed the TSP to investigate improving juvenile fish passage through the turbine environment for the Corps projects located on the Snake and Columbia Rivers. The basis for this program is reported in the Columbia River Salmon Mitigation Analysis System Configuration Study Phase I, Appendix F, dated April, 1994. This report was prepared in response to the NPPC's Columbia Fish and Wildlife Program. Section 6, titled "Turbine Passage Survival", describes the mechanisms that are the possible causes of fish injury and mortality by passage through turbines. These mechanisms include abrasion, strike or physical impact, shear, rapid pressure changes, and cavitation. The report identified that further investigation is necessary to quantify the parameters and also indicated that survival through the hydrosystem for many Columbia River salmon stocks could be increased with improved turbine passage conditions.

The PSP was developed for the TSP to outline the activities which will be undertaken to conduct the investigation of short term and possible long term solutions to improve turbine passage. The investigation will conclude with implementation recommendations, after which a decision will be made to determine if turbine studies will continue into Phase II. . The follow up work will refine and verify the best alternative through prototype testing to ensure it meets defined biological performance criteria.

The findings from this study will be incorporated into improved turbine operations as soon as possible and, if feasible, recommendations for future turbine rehabilitation programs will be made. The benefits to salmon stocks are potentially significant and cannot be ignored, since they would accrue over the life of a rehabilitated turbine, which is estimated to be 35-50 years. Since there are a large number of turbines that will eventually be rehabilitated, the development of new turbine designs that increase fish survival over existing conditions should occur as soon as possible to ensure the new designs can be incorporated into scheduled turbine rehabilitation programs.

The PSP was developed in coordination with activities being conducted by other organizations, such as Public Utility Districts (PUDs), DOE, EPRI and BPA. This coordination was done to eliminate duplication, reduce cost and enhance the effectiveness of the Corps' turbine program (results from these related programs are discussed in Section 4). The COE study is intended to provide a comprehensive evaluation of the effects of the turbine environment on fish survival, first by physical modeling and then prototype testing on a base case unit. The difference between this program and the other related activities is that by integrating biological, engineering and hydraulic modeling disciplines and conducting all tests on a single unit configuration, definite conclusions can

be drawn regarding tracing the route of fish through the turbine, collection of data on the pressures and velocities along that route and the effect of those conditions on the fish. None of the related activities have a comprehensive plan such as this. The information obtained from this program will be incorporated with information obtained from other programs, allowing for comprehensive recommendations to be provided on which strategies or combination of strategies should be implemented or investigated further.

2.2 PROGRAM OVERVIEW

The TSP has been divided into three distinct yet integrated tasks: biological studies, engineering studies and hydraulic modeling. These three tasks are linked functionally and across fiscal years; each year builds on the results from the previous year. The scope of work for the project consists, in part, of using a basecase turbine and site dedicated for engineering and biological prototype testing. The prototype tests will be performed on the selected unit for existing conditions and modifications to existing operations to obtain baseline information. Hydraulic modeling of existing conditions will provide additional information that cannot be collected from the prototype studies. Engineering testing consists of index testing, flow measurement, imaging investigations and pressure distribution testing.

2.2.1 Biological Studies

The biological prototype testing consists of fish survival and condition studies, and fish route/distribution studies. The purpose of the fish survival and condition studies is to determine mortality and injury rates due to turbine passage under current conditions and operations. The assessments will be made using the balloon tag methodology. This will allow fish that have passed through a turbine to be recaptured in the immediate tailrace. Fish will be released at various points in the turbine intake. These release points will be selected based on hydraulic model studies of the turbine passage environment. Fish will be passed through areas where injury and mortality are suspected to occur, and cause and effect relationships will be developed between the area of concern and fish condition. These studies will be conducted at McNary Dam Unit 5.

A study of fish distribution with turbines will be conducted. The primary purpose of this component of the TSP is to compare fish trajectories to results from physical hydraulic model studies to determine if we can rely on the physical models in the future to evaluate various turbine design improvements or alternatives. The fish distribution study is comprised of three phases: First, coordinate and develop a methodology, along with associated equipment, for use within the turbine environment to determine within turbine fish distribution. Second, prototype test the selected equipment and methodology. Third, determine/map fish distribution within the turbine environment under a range of operations.

In addition to the studies at McNary Dam, biological testing of a new MGR will also be conducted under the TSP. MGRs are being installed at Bonneville First Powerhouse as

part of an ongoing rehabilitation program. The first MGR is schedule to be installed beginning in 1998.   Fish will be released at various locations and turbine loadings to provide an overall assessment of MGR performance. Results from this study will determine whether MGR designs should be considered for installation at other Snake and Columbia River powerhouses through upcoming rehabilitation programs.

2.2.2 Engineering Studies

Initial prototype testing will "tune" the McNary and Bonneville First Powerhouse turbines for optimal performance with and without fish diversion devices. Operational modifications testing consists of testing the base case unit under various operating points to investigate the wicket gate/blade angle combination that optimizes fish passage conditions. Initial index testing will be performed to assure turbine operating conditions are consistent with the design and present operating parameters. After establishment of "on cam" performance with and without fish screens, abbreviated field testing will be performed to assure "on cam" operation of the prototype prior to biological testing. In the second and third years of the program, operational modifications will be considered and biological tests will evaluate biological benefits of the operational modifications, if needed. Long term installation of instrumentation and data acquisition equipment for monitoring turbine operation will be required to maintain definable turbine operating conditions during subsequent biological and turbine modification field testing. It is expected that an index test will be performed annually for at least three years to confirm correct operation of the turbine during biological testing.

Index measurement equipment consists of a set of transducers (pressure, differential pressure, linear, rotational, water level and power measurement), data acquisition and recording equipment and computer monitoring, reporting and data reduction equipment. This equipment will be dedicated for field testing on the baseline unit, McNary Unit 5.

The turbine intake will initially be instrumented with sonic measurement equipment suitable for estimation of the quantity of flow and water velocity profiles.

2.2.3 Hydraulic Modeling

Physical hydraulic models will be used to evaluate the hydraulic conditions within the turbine passage way. Sectional models of the powerhouse intakes will be used to define both turbine performance characteristics as well as fish related hydraulic conditions. A performance model for the McNary Turbine unit was built by a private turbine contractor. Sectional models designed specifically to examine hydraulic conditions within the intake and turbine areas were built at the Corps of Engineers WES, located in Vicksburg, Mississippi, for both the McNary and Bonneville Projects.   The McNary model will include a model turbine, the downstream draft tube, and the exit to tailrace, which will allow for detailed examination of the complete passage route of water through the turbine environment.. The Bonneville model will only be modeled through the wicket gates and stay vanes.   These models are made of clear plexi-glass which allows for high visibility

and easy data collection. A non-intrusive laser Doppler velocimeter, neutrally buoyant beads, dye, videotape and photography are being utilized to collect data and visualize flow patterns and fish passage routes.

Initial testing of baseline conditions is being performed on the McNary model, which will aid in identifying possible problem areas within the turbine environment. Areas to be studied include the flow patterns at the intake, wicket gates and stay vanes, the turbine runner, the length of the draft tube and draft tube discharge. Flow patterns to be evaluated include water velocity, flow direction, formation of vortices, rapid decelerations and accelerations, and turbulence. Information from this testing will provide input on key locations for instrumentation of prototype engineering and fish release locations for the biological testing, in addition to providing critical data necessary to determine direction and set priorities for future efforts.

2.3 SCHEDULE

The PSP was designed and approved as a three year program, beginning October 1, 1996. Since the inception of the program and the approval of the PSP, several unexpected events have occurred which have impacted initial program schedules, including:

(1) Program funding and therefore initiation of work did not occur until the middle of FY97 (April, 1997). This resulted in effectively shifting schedules back by approximately six months from those originally approved.
(2) Funding for FY98 was reduced by Congress for the entire Columbia River Fish Mitigation Program, of which the Turbine Passage Survival Program is a component. This has resulted in the extension of the program for an additional year, since some portions of the program scheduled for FY98 have been delayed due to funding cuts.
(3) Due to unsuspected damage to the generator of Unit 6 at Bonneville, which must be repaired prior to installation of the MGR, the MGR biological testing will not take place until FY99, instead of FY98 as originally scheduled and approved.
(4) A critical path item that was not anticipated prior to October, 1997 is the requirement for the building and installation of a set of stop logs, needed in order for dewatering to take place prior to completion of the MGR biological studies. Bonneville First Powerhouse has two sets of stop logs already constructed, but both will be in use by the turbine rehabilitation contractor during the period that dewatering for the MGR biological studies needs to occur. This component was added to the FY98 program.

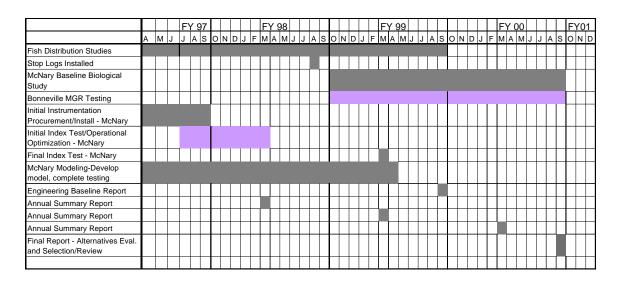A current multi-year schedule is shown in Table 1.

	FY 97				FY 98												FY 99										FY 00							FY01
	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Fish Distribution Studies	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██																			
Stop Logs Installed														██																															
McNary Baseline Biological Study																			██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██					
Bonneville MGR Testing																			🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪					
Initial Instrumentation Procurement/Install - McNary	██	██	██	██																																									
Initial Index Test/Operational Optimization - McNary			🟪	🟪		🟪	🟪	🟪																																					
Final Index Test - McNary																				██																									
McNary Modeling-Develop model, complete testing	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██	██																							
Engineering Baseline Report																															██														
Annual Summary Report											██																																		
Annual Summary Report																					██																								
Annual Summary Report																																				██									
Final Report - Alternatives Eval. and Selection/Review																																										██			

Table 1. Current Turbine Passage Survival Program Schedule In Fiscal Years

2.4 BUDGET

The current budget is significantly different than that originally conceived in the PSP, for the reasons described in paragraph 2.3. The Turbine Passage Survival Program was designed and approved as a three year, $7.6 million dollar project. It has now been modified to a four year, $6.6 million dollar project. The current multi-year budget is shown in Table 2.

Activity	FY 97	FY 98	FY 99	FY 00
Fish Distribution Studies - MIPR	$262,000	$65,000	$300,000	
McNary Baseline Biological Contract			$600,000	$600,000
Stop Log Contract		$346,000		
Bonneville MGR - Contract		$34,000	$800,000	
Initial Instrumentation Procure/Install - McNary - Contract	$495,000			
Initial Index Testing/Operational Optimization - McNary	$110,000	$110,000	$145,000	
Final Index Test - McNary	$50,000	$85,000	$145,000	
McNary Model - Design Model, Develop Techniques - MIPR	$235,000	$440,000	$120,000	
McNary Model - in-house labor	$88,000	$120,000	$75,000	
Engineering Baseline Testing Report			$154,500	
Annual Report		$50,000	$50,000	$50,000
Final Report				$191,000
Support Activities	$55,000	$150,000	$275,200	$97,300
Yearly Totals	**$1,295,000**	**$1,400,000**	**$2,664,700**	**$938,300**

Multi-year Total = $6,298,000
Contingency = $314,900
Project Total = $6,612,900

Table 2. Current Turbine Passage Survival Program Cost Estimate

SECTION 3

FY97 TASK SUMMARIES

3.1 BIOLOGICAL STUDIES

The biological studies portion of the TSP in 1997 focused on study design development, planning, and equipment procurement and commissioning.   Progress made to date is summarized below for each study.

3.1.1 Minimum Gap Runner Testing at Bonneville First Powerhouse

3.1.1.1 General

Post construction biological evaluation and MGR testing was originally scheduled for the fall of 1998 after completion/installation of the MGR at Bonneville Unit 6. The installation of the MGR was delayed, however, which delayed the fish condition and survival tests until the spring of 1999. Following is a summary of the work completed in 1997 towards development of a study plan, including equipment and an engineering review to develop and design test fish release apparatus.

3.1.1.2 Study Objectives

The goals of the MGR test at Bonneville First Powerhouse are to:

(1) Monitor the newly installed MGR and estimate survival and condition of fish passing the unit;
(2) Determine whether installation of additional MGR units will help achieve the recovery goals outlined in the NMFS 1995 Biological Opinion; and
(3) Gain information regarding fish condition and mortality that will be used in the TSP to develop more "fish friendly" turbines.

The objectives required to fulfill the study goals are:

- Objective 1: Obtain overall survival/fish condition estimates with a precision of +/-3%, 90% of the time for an existing unit and an MGR unit operating at peak efficiency. Monitor fish injury types and condition to ensure that the MGR unit provides a fish passage environment at least as safe as the existing units. The overall survival/fish condition estimates will be pooled estimates for fish released at three locations that carry them near the blade tip, near the hub, and a "MIP" or Minimum Injury Path release for both turbines. Also, test to determine if the overall survival rate for the MGR unit is statistically higher than the existing unit at a power of $1-b=0.80$ and a significance of $a=0.10$.

- Objective 2: Obtain survival estimates with a precision of +/-3%, 90% of the time for fish passing the blade, hub, and MIP in the MGR unit and existing unit operating at peak efficiency. Also, test to determine if the survival estimates for the three routes of passage through the MGR and existing units are different statistically at power of 1-b=0.80 and a significance of a=0.10. These tests will be conducted at peak efficiency.

- Objective 3: Increase the precision of the comparison between the MGR unit and existing unit to +/-2%, 90% of the time for both units.

- Objective 4: Obtain survival/injury estimates with a precision of +/-3%, 90% of the time from an existing and MGR unit for fish passed through each unit, with both units operating outside the one percent operating range.

3.1.1.3 Study Design

This study will involve releasing balloon tagged juvenile salmonids through various routes in a turbine unit. This involved using a 1:25 scale hydraulic model of the Bonneville First Powerhouse, located at WES, to identify release points in the turbine intake that will allow fish to pass the turbine runner in areas that are suspected of causing injury (i.e. near the hub and the blade tip). These are the areas of concern that have been addressed by the MGR.

Soon after the fish are released (and after they pass the turbine), the balloon tag will inflate, forcing the fish to the surface where they can be recovered in the tailrace. Each fish will also be tagged with an external radio tag to aid in recovery. Immediately upon recovery, tags will be removed and the fish will be examined for external injury. The fish will then be transported to a holding pond and will be held for 48 hours and then be examined again to determine delayed effects and mortality.

3.1.1.4 Release Points

Members of the TSP team met at WES for the purpose of discussing the use of the hydraulic models to assist in the development of release points within the turbine for the study. While the main focus of the discussions on fish release points was McNary, the same information will be applied to Bonneville for the MGR studies.

The release points will be based on the anticipated fish path as it passes the turbine unit. The idea behind these releases is to attempt to isolate areas of fish injury within the turbine. Fish releases were developed using neutrally buoyant beads in the physical model to direct fish/beads to pass in a specific area where it was thought injury may occur and where specific improvement in the turbine has occurred (MGR unit). The release points were chosen to allow a fish to pass through an area of concern and then have the rest of the passage be along what has been identified as the MIP. At Bonneville, three release "paths" were identified in FY97. In addition to a tailrace release, the release points were

selected to have fish pass the blade tip, the hub, and the MIP. These releases will be made in both the MGR and an existing unit.

3.1.1.5 Estimated Fish Numbers and Precision of Estimates

The number of fish required for this study are dependant on several factors.   The recovery rate of treatment and control fish, the survival of treatment and control fish and the expected survival/injury rates of treatment fish as well as the expected precision all play a factor in determining the number of fish used. For this study design, some assumptions were made for calculation of expected fish numbers. A 98% recovery of control fish, 98% survival of control fish, and a 92-98% survival of treatment fish (dependant on release) was assumed. The expected level of precision was +/-2% or 3%, depending on the objective.

Based on these assumptions, the following is an estimate of the number of fish required for each release point and expected level of precision. It should be noted that due to the nature of the test and the almost immediate results, fish numbers can be modified daily, if required, to achieve the desired precision of the estimate.

Option 1:   Blade tip = 240 fish (for each unit)
                        Hub   = 240 fish (for each unit)
                        MIP   = 240 fish (for each unit)
                        Control   = 720 fish total
                        SUB TOTAL   = 2160 fish

Option 2: *Note: fish needed for option 2 are ADDED to fish needed for option 1*
                        Blade tip = 160 fish (for each unit)
                        Hub   = 160 fish (for each unit)
                        MIP   = 160 fish (for each unit)
                        Control   = 160 fish total
                        SUB TOTAL   = 1120 additional fish

Option 3: *Note: fish needed for option 3 are ADDED to fish needed for options 1 and 2*
                        Blade tip = 200 fish (for each unit)
                        Hub   = 0 fish (for each unit)
                        MIP   = 0 fish (for each unit)
                        Control   = 200 fish total
                        SUB TOTAL   = 600 additional fish

Total fish required to complete all objectives is 3880.

3.1.1.6 Schedule

This study is scheduled to be completed in the fall of 1999. It is, however, dependent upon the scheduled installation of the MGR unit and the availability of funding in FY99.

3.1.2 Fish Condition/Survival Testing at McNary Dam

The objective of this study is to determine causal mechanisms or areas of injury to juvenile salmonids within the turbine environment through multiple releases of fish into the turbine intake.

The study will use the "balloon tag" or "Turbn' Tag" methodology to measure direct mortality and injury of juvenile fish passing through the turbine environment from multiple release sites in the turbine intake. The fish release points, which will be made in specific locations to identify the effects of passage through specific areas in the turbine, were determined using a 1:25 sectional turbine model at WES. Release points will be selected to place fish in an anticipated "path" through the turbine passage in an attempt to isolate areas of potential injury (i.e. near the hub, at the blade tip, near the intake roof, wicket gates, etc.). The number of release points is expected to be approximately three, plus tailrace releases.

The turbine unit for this study will be Unit 5 at McNary Dam. The turbine will be tested under one flow condition.

Fish will be released immediately upstream of the turbine distributor and recaptured in the tailrace below the Project. Tailrace releases will be made downstream of the turbine boil. Fish will then be inspected for injury and mortality. Fish that are recaptured alive will then be held in circular tanks for 48 hours to determine any delayed mortality.

The use of Passive Integrated Transponder (PIT) tags was considered for the first year of study to help understand some of the indirect effects of turbine passage. Since the main objective of the first year of study, however, is to identify areas within the turbine that cause direct injury to juvenile salmonids, it was decided that the balloon tag methodology was best suited for collection of direct injury information. The use of PIT tags in the second year of study will be considered, to assess both the direct and indirect components of turbine mortality.

3.1.2.1 Release Points

The release points will be based on the anticipated fish paths as they pass the turbine unit. The idea behind these releases is to attempt to isolate areas of fish injury within the turbine passage. Fish releases were developed using physical models at WES to direct fish to pass through a specific area where it is thought injury may occur. For example, the potential for injury when a fish strikes a wicket gate will be studied by releasing a fish such that it has a high potential of striking the wicket gate (based on particle modeling) and then follow the MIP the rest of the way through the turbine. This will allow the isolation

of areas of concern within the turbine passage. Through physical modeling and use of neutrally buoyant beads placed in the model, the team developed several areas of concern. It appears injury may be occurring (based on studies with neutrally buoyant beads) when fish strike the wicket gates and stay vanes, fish pass the blade tip, fish pass the hub, and fish strike the draft tube pier. Priority will likely be placed on the wicket gate/stay vanes and blade tip (or hub, but not both) for the first year of study. The draft tube pier was noted as an area of concern by several team members, but it was not possible to release beads/fish in such a way as to isolate this area of concern.   Also, after viewing the model in FY97, it was determined that blade strike did not occur at any definable point and that it would be difficult to set up fish releases with a high probability of strike on the blade, although it is noted that blade strike has been mentioned by other authors as an area of concern.

3.1.2.2   Estimated Fish Numbers and Precision of Estimates

The number of fish used will be approximately 250 per release (test and control). The results from this test will not be used to compare injury/survival between release points but to assist in determining where injuries occur within the turbine environment. This release size will allow detection of approximately +/-3% differences between the control releases and test releases. This precision should be sufficient to determine if and where, relative to targeted areas of concern within the turbine environment, the injuries are caused and to statistically determine whether there is a difference in survival between release groups.

3.1.2.3 Schedule

It is anticipated that this study will occur in the spring of 1999.

3.1.3 Fish Distribution through Turbine Passage

An important component of prototype test results is fish distribution through the turbine passage. After biological results from prototype tests are available, the number of fish that would be passing through injury areas needs to be quantified in order to evaluate their impact on species survival. An area that causes high damage to a small number of fish may be of less concern than an area with more moderate fish damage, but larger numbers of fish passing through.

In order to estimate fish distribution, existing distribution information will be used to set up a computer model. This information will be used to evaluate the likelihood that fish will enter anticipated injury areas identified in the fish passage model and prototype.

3.1.4 Fish Trajectory Mapping

The in-turbine fish trajectory-mapping task requires the use of ultrasonic and imaging technology. In FY97, the data acquisition portion of an ultrasonic fish tracking system was designed and released for bid. Bids were obtained from qualified vendors and a contract awarded for construction of the data acquisition portion of the tracking system. Three additional elements that were also developed in FY97: an ultrasonic transmitter, a neutrally buoyant package for the ultrasonic transmitter and light emitting tag, and software to process data and to assist with deployment of the tracking system.

Three different contractors are pursuing the ultrasonic transmitter, ultrasonic tracking system and processing of tracking system output, and the tracking system data analysis software. WES is pursuing development of the neutrally buoyant package for the ultrasonic transmitter and light emitting tags. All tracking system elements are scheduled for delivery, integration, and initial testing in FY98.

420 kHz ultrasonic "beeper" (non-coded) transmitters will be used for tracking both fish and neutrally buoyant objects. The transmitters are unique in that they have a high transmission repetition cycle and will operate at maximum output power for a short period of time. The transmitters will emit 10 pulses per second at the maximum power that the transmitter piezoelectric material can tolerate over a five-minute active life. The transmitters are designed for the minimum size consistent with the above requirements. There may be changes in the design of the tag following in-field testing of prototypes scheduled for FY98. Of particular concern is the source level of the transmitter required to optimize signal to noise at the receiver at maximum expected tracking distances.

The data acquisition portion of the tracking system consists of both hardware and software elements. The tracking system hardware consists of 4 wide beam transducers, cable, 4 transceivers, and a high speed, multi-channel data acquisition board operating in a computer. The operating frequency of the split-beam system will be 420 kHz. The system is designed for both active and passive operation. The system will be deployed so that a portion of the turbine intake downstream from the point of release of ultrasonic transmitter tagged fish is within the higher gain portion of the receiving directivity of the system transducers. Immediately following release of a tagged fish, all 4 system receivers will be turned on and the output of the receivers digitized and stored in computer memory. The emphasis of the first stage of data acquisition is to maximize the recovery of raw data for subsequent processing. It is expected that several hundred megabytes of raw data will be acquired in the 1 minute or less needed for the tagged fish to pass through the monitored portion of the turbine intake. The raw data will be archived, then processed. Processing of the raw digitized data and estimation of the "pointing angles" to the transmitter from each transducer in the receiving array are the principal tasks for the software portions of the tracking system. Processing will consist of a variety of signal processing steps to detect the direct path transmissions from the ultrasonic transmitter to each system transducer and to estimate the direction of the transmitter relative to a reference point within the plane of the system transducers. An estimate of the direction of the transmitter relative to the reference point will be obtained for each transducer and each

detected transmission during passage of the tagged fish through the monitored region of the turbine intake. These direction estimates will be the primary output of the data acquisition portion of the system and the input to the data analysis software discussed below.

Baylor University in Waco, TX is developing the data analysis portion of the tracking system. The ultrasonic transmitter direction estimates from the data acquisition portion of the tracking system will provide input for two primary data analysis functions. The first function of data analysis will be to estimate the location of the ultrasonic transmitter for each transmission detected by the data acquisition system. Since it is very unlikely that the lines of sight from the receiving transducers to the transmitter will overlap in the three-dimensional space of the turbine intake, an estimate of transmitter location that considers the distance between the lines of sight is necessary. Several different methods for obtaining estimates of transmitter location are being considered. When completed, the data analysis software will provide an estimate of the location of the transmitter, and the error associated with those estimates, for each detected transmission as the transmitter passes through the monitored portion of the turbine intake. These estimates will be further analyzed to obtain a three-dimensional trajectory for each transmitter and to perform tests of hypotheses that fish behave like neutrally buoyant objects during their passage through a turbine intake.

The second function of the data analysis software element of the system will be to analyze data obtained from tracking particles through the intake of the 1:25 physical turbine environment model. This analysis will be performed using model data acquired for release points selected for prototype tests of the trajectory of inanimate objects and fish passing through a turbine intake. The objective of the analysis will be to estimate the location and aiming angles for the data acquisition system transducers that will optimize estimation of the location of the ultrasonic transmitter. This is the inverse of estimation of the location of the transmitter given the angles for the lines of sight to the transmitter from the tracking baseline transducers. This approach will make maximum use of some of the data to be acquired using the 1:25 turbine environment physical model and will also greatly facilitate the design of the tracking system baseline for each in-turbine release point.

All elements of the ultrasonic tracking system, the transmitter, neutrally buoyant package, and the data acquisition and data analysis subsystems are scheduled for delivery by mid-April in FY98. Following delivery, work will continue with vendors through a period of commissioning, during which the performance of the system elements will be evaluated in laboratory and field trials. It is expected that commissioning of the system elements will take several months because of the complexity of the system.

In addition to the above activities for the ultrasonic tracking system, several miniature light sources were evaluated during FY97 for use as a light emitting tag for both neutrally buoyant objects and fish. An ultra-bright white light emitting neon miniature light was selected for further evaluation use. Experience was also obtained working with off-the-

shelf color and black and white video cameras in Snake River water during the period of the smolt outmigration. Clusters of ultra-bright miniature lights provided detection ranges of several meters over a typical range of water clarity conditions. While progress has been made with evaluation of potential light emitting tag sources, the challenge of mounting video cameras within the turbine environment remains untested. Opportunities may become available in FY98 to make progress in this area, although no specific in-turbine tests have been planned. Laboratory and in-field evaluation of light emitting tags and associated video cameras will continue in FY98.

3.1.5. Statistical Model for Estimation of Overall Turbine Survival Rates

Limited work was completed in the development of a model that would incorporate data from the survival/injury studies and fish trajectory mapping study, as well as past vertical distribution data, and develop an overall survival estimate that could be mapped back to the population at large. It is expected that this work will be completed by Dr. John Skalski of the University of Washington. The model will use a series of conditional probabilities to develop overall fish survival estimates and will be based on straightforward principles of probability theory. The challenge will be to ensure that data from the survival and fish trajectory studies is collected in an appropriate manner for the numerical analysis of the results.

3.2 ENGINEERING STUDIES

3.2.1 General

Engineering investigations identified in the PSP consisted of turbine operational optimization studies, turbine environment studies and turbine design studies. Each of these areas would be examined with both turbine model and prototype testing and evaluation. In FY97, two prototype sites for biological and engineering testing work were identified as:

- McNary Unit 5, selected by the Corps and approved by the Region for evaluation of existing Kaplan turbines. The program calls for examining and evaluating fish mortality in an existing Kaplan turbine and evaluating the effects on fish mortality of operational and design changes to an existing turbine. The work is to include investigations into the possible mechanisms within the turbine which affect fish survival and develop and investigate design solutions which reduce (or eliminate) juvenile fish injury or mortality. Recommendations for design improvements developed in Phase I would, if funded be evaluated in Phase II of the TSP.

- Bonneville First Powerhouse rehabilitated turbine. Additional engineering and economic evaluations of the replacement turbine runners for the Bonneville First Powerhouse were added to the TSP during the approval process of the PSP. Features which improved turbine efficiency and should reduce likely sources of turbine juvenile fish injury or mortality were included in the design and procurement of a replacement

Kaplan turbine identified as a MGR has been undertaken.   In order to evaluate the effects of the MGR on juvenile fish passage and to determine whether MGR's should be considered in future turbine rehabilitation programs, engineering and biological tests comparing an existing Bonneville Kaplan turbine to the MGR were added to the TSP program during FY97.

3.2.2 Operational Optimization

The operational optimization of McNary Unit 5 consists of performing turbine Index testing to identify operating conditions that are consistent with the design and present operating parameters. This testing will assure that the turbine(s) are operating as efficiently as possible prior to actual biological testing. This field Index testing is to be performed with and without fish diversion devices in place and is scheduled to occur in FY98. In order to perform such field testing, three areas of work were completed in FY97:
 (1) Procurement and installation of dedicated field testing equipment for performance of a standard field Index test. (2) Procurement and installation of flow measurement equipment to calibrate existing relative flow measurement piezometric taps and establish the optimum turbine "on cam" runner blade to wicket gate relationship. (3) Development of possible optimized "on cam" relationships from known field and model test data, suitable for use in the existing Unit 5 3-D cam controller unit.

3.2.2.1 Procurement and Installation of Field Testing Equipment

In order to perform field testing in a reasonable time frame and to monitor turbine operation during biological testing, long term installation of instrumentation and data acquisition equipment is required at McNary. In FY97 the procurement, planning and partial installation of test equipment was scheduled for McNary and Bonneville First Powerhouse.

The engineering work accomplished in FY97 for the McNary project was the procurement of 10 transducers which will measure power, wicket gate angle, servomotor stroke, absolute pressure at two locations and differential pressure.   The procurement included obtaining the computer and data acquisition equipment, the cabling, miscellaneous appurtenances and the training. Preliminary design of mountings, scales and interface were completed or initiated. Specific training for the use and programming of the computer and data acquisition equipment was scheduled. A brochure describing the required field testing and site requirements was published. The unwatering and mechanical calibration of the turbine runner blades and wicket gates was performed. The field testing and identification of piezometric taps was completed. During the mechanical calibrations, difficulties with the existing Seawell 3-D governor electronic control unit (ECU) were encountered, requiring additional investigations into adaptation of the field test equipment to the ECU input and output requirements.   The investigations revealed that the ECU input and output configuration was unsuitable for direct connection to the field test data acquisition equipment. Design and procurement of a suitable interface for

field test measurement equipment to the Seawell ECU and field test data acquisition equipment was initiated.

The engineering work accomplished in FY97 for the Bonneville First Powerhouse comparative field testing consisted primarily of planning, scheduling and coordination between the Powerhouse Rehabilitation Team, the Bonneville Project Operations Team and the TSP Team. Two items of the turbine field testing work were identified which will require future coordination and resolution: (1) The unavailability of sufficient turbine unwatering equipment to perform the necessary turbine mechanical calibrations of an existing unit, and (2) The disposition of the intake emergency gates for installation of the scintillation flow measurement system. It has been tentatively coordinated that Units 5 and 6 will be the units field tested in FY98 or FY99, depending on the rehabilitation progress made on Unit 6.

3.2.2.2 Procurement and Installation of Flow Measurement Equipment

The work accomplished in FY97 included the design, plans and specifications and contract award for procurement of a Scintillation flow measurement system, including six mounting frames (3 frames for McNary and 3 frames for Bonneville First Powerhouse). A 16 foot trailer to house and secure the scintillation flow measurement system for storage and transport was also purchased. The equipment is to be delivered in FY98.

3.2.2.3 Development of Optimized "On Cam" Relationships

The development of "on cam" relationships were derived from three separate sources initiated under a Walla Walla District contract: (a) Different performance modeling techniques, (b) Piezometric tap investigations and, (c) Turbine performance modeling compared to WES modeling techniques as well as other model-to-prototype comparisons. The data from this contract was to be used to develop a method for derivation of turbine "on cam" blade/gate relationships with fish screens installed in the intake of a McNary turbine.

During FY97, the derivation of the full range of "on cam" curves from a 1993 field Index Test was installed in McNary Unit 5 ECU for with and without screen conditions. Derivation of the "on cam" curves predicted by Froude and Reynolds model testing techniques began in FY97 and will proceed into FY98 as the turbine performance model testing data is received from the contractor. The "on cam" curves developed from the 1993 Index test, the Froude model test and the Reynolds model test for conditions with and without fish screens installed will be tested in the FY98 field test.

During FY97, the derivation of the full range of "on cam" curves for Bonneville First Powerhouse Unit 2 without fish screens installed was completed. However, the Index test data for the with-screen conditions is still being evaluated because the recorded data is inconsistent with the no-screen data.

3.2.3 Turbine Environment Studies

3.2.3.1 General

The purpose of these studies is to better define, in engineering terms, existing conditions within the turbine water passage environment. The studies consist of quantifying conditions within a turbine during operation. Both laboratory and prototype work will be performed to attempt to identify hydraulic and engineering design criteria limits. These limits can then be biologically evaluated to determine if a causal effect between the turbine environment and fish mortality exists. Three areas to be investigated under this program include: (1) turbine environmental imaging, (2) prototype pressure distribution, and (3) coordination with WES hydraulic studies. These tasks were identified by the TSP team as a lower priority or incidental work; accomplishments are identified elsewhere in this report.

3.2.3.2 Turbine Environmental Imaging

The purpose of turbine environmental imaging is to investigate the interior of a turbine water passage and how juvenile fish may respond to the turbine environment. No work specific to turbine environmental imaging was performed in FY97.

3.2.3.3 Prototype Pressure Distribution

During FY97, two existing piezometric taps in the turbine intake were selected for recording gauge pressure during the future McNary Unit 5 field test. Measurement of six water passage sections in a model turbine test, being performed on a Lower Granite Kaplan turbine, was also added to the required model measurements.

3.2.3.4 Coordination with WES Hydraulic Studies

In FY97, basic observational testing was done utilizing the assistance and experience of WES to determine what, where and how to measure various water passage parameters of engineering and biological interest. This is described in detail in Section 3.3.

3.2.4 Turbine Design Studies

3.2.4.1 General

The proposed investigations are to incorporate numerical modeling, hydraulic modeling and turbine performance model testing with prototype field measurements to better define, in engineering terms, the physical conditions within a turbine water passage. After initial definition of turbine water passage conditions, application of turbine environmental and juvenile biological limits to the predicted turbine water passage conditions will be made. Results will indicate potentially dangerous or unsatisfactory areas or mortality mechanisms within an existing turbine water passage. These areas will then be examined in the WES

models to assess biological impacts and to determine if design modifications can be made to these areas to improve fish passage conditions. In the future, these modifications may be turbine performance modeled and, if results are successful, the design changes may be incorporated into an existing prototype design and field tested to determine improvements in juvenile fish passage survival. The existing PSP calls for initial investigative work by three modeling methods: (1) Computer Numerical Modeling, (2) WES Hydraulic Modeling, and
(3) Turbine performance model testing. These three investigative techniques are to be coordinated with other on-going turbine environmental studies, modeling and prototype field testing efforts.

3.2.4.2 Computer Numerical Modeling

Computer numerical modeling, called computational fluid dynamics (CFD), has been used by industry for some years to develop preliminary turbine designs for actual hydraulic turbine performance model testing. The DOE, through the Advanced Hydropower Turbine System Program (AHTS), utilized the CFD analysis beyond the design of Kaplan turbine runner blades. The initial work, outlined in the PSP for FY97, was to develop plans and specifications for procurement of services to develop the McNary Unit 5 CFD model. The CFD model would be calibrated and tested using model and prototype measurements to assure reasonable results were obtainable. After development of an acceptable CFD model, design modifications to the existing turbine model could be made to assess the resulting hydraulic and turbine performance impacts.

During FY97, engineering investigations of existing CFD methods, accuracy and availability were made which resulted in the development of draft plans and specifications to procure the work. Legal concerns regarding Intellectual Property Rights, poor results from other on-going CFD work and lack of necessary detail effectively terminated any additional work in this area.

3.2.4.3 WES Hydraulic Modeling

Information on hydraulic modeling at WES is provided in Section 3.3.

3.2.4.4 Turbine Performance Model Testing

During FY97, results of various turbine performance model tests which were funded outside of the scope of the TSP were incorporated into the hydraulic modeling at WES. Data obtained from these tests were also used in the development of prototype test plans for the FY98-99 engineering and biological field tests at McNary and Bonneville. Reference Section 4.6 for additional information.

3.3 HYDRAULIC MODELING

3.3.1 General

The PSP defines the need to understand the hydraulic conditions within the turbine environment in order to develop reasonable solutions to the problem of fish passing through turbines. However, trying to understand what is happening within a prototype turbine on the Snake and Columbia River is extremely complicated. The conditions are very harsh, with velocities as high as 50 fps., rapid pressure changes, rapid flow de-accelerations, high levels of shear, and constantly changing relationships between water flow and rotating parts. Other complications include the large size of the turbine passage area, the difficult access due to the depth of the intake, and the limited visibility due to high turbidity. Cameras can only capture a few feet of the water column that may be 20 feet wide, over 45 feet high, and 100 feet long.

The use of hydraulic scale models offer solutions to many of the difficulties associated with turbine study. Two types of hydraulic models are being used in this study: performance models (typically used by turbine manufactures to determine expected turbine performance) and fish passage models (used to examine flow characteristics through the turbine passage); reference Section 3.3.2.1 for more information on these two types of models. Due to the smaller scale, the improved access, and better visibility, options can be built and tested faster in a model than in the prototype, at a much lower cost. Studies are not linked to the fish window, allowing year round testing. These models can also be used to develop prototype tests and provide information for input into numerical models (important for study of the turbine area).

While hydraulic models enhance the ability to understand what is physically happening within the turbine environment, information on how these conditions actually affect fish passage is still required. In addition, it is important to verify that the models are accurately representing prototype conditions. Therefore, it is critical that the model test program be closely tied to a prototype test program (including both physical and biological testing) to verify conditions identified in the models.

3.3.2 Hydraulic Models

3.3.2.1 Turbine Performance Model & WES Sectional Model Testing

Two types of hydraulic models were used to evaluate turbine passage: performance models and fish passage models. During FY97, results of various turbine performance model tests, funded outside of the scope of the TSP, have been incorporated into the hydraulic modeling at WES, as well as in developing the prototype test plans for the FY98-FY99 engineering and biological field tests at McNary and Bonneville. The focus of these models is to determine power and turbine performance issues. Curves and turbine settings related to turbine performance were developed using these models. Since the model is made of steel, limited visual access is available.

Specifically for the McNary effort, different modeling techniques and the effects of fish diversion devices are being investigated by performance models to determine which best

represents prototype turbine performance with fish screens installed in the intakes. Turbine performance modeling is being used to identify the predicted prototype performance response and has been selected over comprehensive prototype field testing because of cost, accuracy and flexibility.

The sectional models built at WES for this study are made of Plexiglas, which allows visual access to nearly the entire turbine passage. Beads and dye were used in combination with high speed photography and velocity laser readings to locate likely fish injury areas (associated with turbulence, bead strikes, etc.). The turbine blade angles, wicket gate angles, and turbine speeds for a given flow condition which were developed in the performance models were used in these models to simulate the prototype.

3.3.2.2 Model Description

The McNary 1:25 scale turbine model is the main model studied for this project; reference Plate A. It represents an entire turbine unit from the entrance through the draft tube outlet into the tailrace. Included are three intake bays, trashracks, intake gate slots, bulkhead slots, fish screens, scroll case, stay vanes, wicket gates, turbine, and draft tube. The model turbine was built by an independent contractor. This contractor also developed performance curves for the 1:25 scale turbine unit with and without ESBS's. Contractor information, along with previous WES model information, were used to calibrate the WES model and insure representation of the prototype.

A Bonneville Dam 1:25 scale fish passage model is also being used in this study. This model represents the intake down to the turbine scroll case (it does not contain an operational turbine, or any components downstream of the turbine) and will be used to help determine fish release locations for biological testing of the MGR turbine scheduled for 1998 installation.

3.3.3 McNary Model Test Set-Up

3.3.3.1 Testing Goals

Model testing goals for the 1997 turbine survival program included the following:

(a) Obtain a qualitative overview of zones through the intake, turbine, draft tube, and tailrace (with and without ESBS's).
(b) Perfect data collection techniques in model.
(c) Locate and understand possible areas of fish injury (strike, pressure changes, velocity, shear, etc.).
(d) Determine equipment placement for fish imaging and pressure measurements in prototype.
(e) Develop a plan for testing critical passage zones in the prototype (including both physical and biological testing).

Future goals for the turbine survival program include the following:

(a) Perfect data collection techniques in prototype.
(b) Develop prototype tests to examine biological impacts of current operation and any proposed improvements.
(c) Identify operational improvements to existing system.
(d) Identify physical improvements to existing system.
(e) Collect information for input into a numerical model of the turbine area.

3.3.3.2 Data Collection Techniques

Techniques used to collect data in the model include:

(a) Neutrally buoyant beads. These were used to identify flow lines and determine possible fish hazards (such as "strike") downstream of the intake gate slots.
(b) Dye tracings. Dye was used to confirm bead paths.
(c) High speed video. Three different video speeds were used to record bead paths. Video was shot at 500 frames per second near the wicket gates, 1000 frames per second in the turbine area and 240 frames per second in the draft tube.
(d) Digital photography. Digital cameras (shooting at speeds up to 100,000,000 frames per second) were used to provide stop action photos of bead passage, turbine, etc..
(e) Two dimensional laser. Two dimensional laser measurements were used to calibrate the WES model. Velocity measurements between previous WES data, independent contractor data, and current model operation were compared.
(f) Three dimensional laser. This laser will be used to obtain three dimensional flow information in the turbine and wicket gate areas.
(g) Pressure readings. Pressure readings will be used to double check prototype and numerical model information.

More information on data collection techniques can be found in Appendix A.

3.3.3.3 Zone Definition

The turbine passageway was divided into eight zones for study; reference Figure 1. Zone numbers on Figure 1 correspond with those on the following list. Zones will be looked at one at a time and combined for a complete evaluation of the flow lines and patterns from the entrance to the tailrace exit. The following zones are presented in their order of study:

(1) Intake gate slot through start of scroll case.
(2) Scroll case.
(3) Stay vanes, wicket gates, and turn into turbine area.
(4) Turbine runner and hub.
(5) Draft tube expansion and elbow to pier nose.
(6) Draft tube pier nose to exit.

(7) Draft tube exit into tailrace.
(8) Intake entrance to intake gate slot.

The intake entrance to intake gate slot section will be evaluated last to simplify flow line analysis with ESBS's installed. Since ESBS's cause major flow disturbances (such as turbulence and redistribution of flow), it was determined that the best way to analyze turbine passage was to concentrate on conditions downstream of the ESBS's. The area upstream of the ESBS's will be studied to determine the extent of flow disturbances, probable flow re-distribution, as well as to estimate potential impacts on non-guided fish.

3.3.3.4 Model Set-up

Model turbine speed was set at 428.5 revolutions per minute (rpm). This is comparable to the prototype turbine speed of 85.7 rpm. Stay vanes were numbered and grids were added (dividing vanes vertically into four equal sections) to aid in identifying bead passage through the vanes. Turbine blades were also numbered. While grids were originally tried on the blades, this was abandoned in favor of a two camera system, which shows three dimensional bead location through the turbine.

The following conditions were used during model testing unless otherwise indicated:

- Turbine flow   12,400 cfs.
- Turbine blade angle   25.75 degrees.
- Wicket gate angle   39 degrees.
- Forebay elevation   340 feet mean sea level (fmsl).
- Tailwater elevation   265 fmsl.

3.3.4 McNary Model Test Results

3.3.4.1 Flow Lines and Fish Paths

(a) General.

Testing in the WES Plexiglas models evaluated flow lines downstream of the intake gate slots to determine possible fish paths and injury areas through the turbine and draft tube. Since velocities in this area are near or above capture velocities (7 fps for six inch fish), flow lines are assumed to approximate fish paths. This assumption will be verified through within turbine fish distribution testing, described in section 3.1.3. Flow lines were studied with and without fish guidance screens installed.

Each intake bay was divided into five sections, vertically. For initial measurements, beads were released in the center of each of these sections just downstream of the intake gate slots in each bay (15 releases in all).   Wicket gates were numbered and divided into four sections vertically. Video cameras were set up to record flow lines of the beads and bead distribution from the intake gate slots through the stay vanes and wicket gates.

These films were later analyzed and the bead path and distribution information recorded on plots such as those seen in Appendix B. Bead paths were verified using dye tracings.

This method was used to identify bead paths, areas of turbulence, and dead zones through the turbine. In FY97, flow lines from the intake gate slot through the wicket gates were completely mapped. Flow lines through the turbine and draft tube were briefly studied and will be analyzed in FY98. Preliminary releases indicated that considerable turbulence existed downstream of the turbine. This turbulence made it difficult to trace the flow path from the entrance to the intake through the zone downstream of the turbine.   It appears that tight control on bead release at stay vanes will be necessary to evaluate passage through the lower portion of the turbine.

(b) Impact of Fish Guidance Screens (extended-length submerged bar screens, or ESBS's) on Flow Lines.

ESBS's are 40 foot long screens set at a 55 degree angle from vertical. They are installed in the McNary intake to increase fish guidance away from turbine passage. Due to guidance benefits and potential hazards of turbine passage, McNary is required to operate with ESBS's installed in all operating turbine units throughout the fish passage season.
Several dams on the Snake and Columbia Rivers are fitted with fish guidance screens (some with ESBS's, some with 20 foot long standard-length traveling screens). Not all intakes, however are screened. Therefore, an important part of this study is to look at conditions through the turbine passage with and without fish guidance screens installed. It is also important to understand the impacts guidance screens have on turbine passage conditions for those fish not guided by the screens.

In general, the ESBS's typically cause beads to spread more vertically and, often, more horizontally as they pass through the wicket gates. Since ESBS's change the distribution of flow, they also affect which wicket gate openings beads are most likely to pass through. This is particularly apparent in the bay A releases and least pronounced in bay B releases. Reference Appendix 2 for graphic representations of these results.

The bottom two releases in each bay represent the majority of the flow that passes under the ESBS's. Where ESBS's have increased the vertical spread of the beads, beads passing lower through the wicket gates would have a greater chance of passing near the outer gap of the turbine blades. Those passing higher may have less of a chance of being impacted by the outer gap. Understanding the zone of influence of the outer gap would help in evaluating the overall expected impact of the ESBS's on fish passage.

Where ESBS's increase the horizontal spread of beads entering the wicket gate and stay vane area, beads often pass through several more wicket gate openings than without ESBS's in place. It is possible that this spread could increase the incidence of strikes on stay vanes and wicket gates by exposing fish to more of these during their passage.

3.3.4.2 *Anticipated Impact of Zones on Fish Passage Based on Model Observations*

The following describes the anticipated impact of various zones on fish condition through turbine passage based on model studies performed in FY97; reference Figure 1 for a zone overview. The portion of the model that is difficult to get detailed measurements is the zone impacted by the rotating runner. This area will be evaluated using more general information such as bead paths, dye, and high speed photography. Another possible method would be the use of a numerical model to analyze this particular area.

       (a)   Intake Gate Slot Through Start of Scroll Case

The turbine intake bay is split into three intake sections. Each section is individually screened by a 40' ESBS. All three intake sections merge into the scroll case; reference Figure 1.

Irregular flow patterns through the intake sections caused by flow redistribution associated with ESBS's result in dead spots (where beads collect) and flow disturbances (with no clear direction of flow). Since velocities in these areas are low, it is unlikely fish injury is occurring due to these flow patterns (though some abrasion injuries may be possible). These patterns could, however, affect fish distribution and orientation.

       (b) Scroll Case, Stay Vanes, and Wicket Gates

Flow from the intake sections enters the scroll case and begins a clockwise flow around the scroll case, past stay vanes, through wicket gates, and down through the turbine; reference Figure 1. Flow along the bottom of the scroll case rises up and then bends sharply down into the turbine. Flow from the top of the scroll case bends sharply down as it enters the turbine. With velocities increasing to about 27 fps as flows pass the wicket gates (for turbine flows of 12,400 cfs), abrasion injuries are possible along the surface of the scroll case.

Stay vanes and wicket gates offer a variety of hazards. As stationary objects in the flow, bead strikes indicate there may be a high incidence of fish strike on the vanes and gates. The gap between the vanes and gates seems to influence the flow patterns. Some beads become lodged between the two, and beads strike the stay vanes and then the wicket gates. Once past the vanes and gates, the turbine pulls flow sharply down. Abrasion injuries along the vanes and the gates are likely, along with strike injuries and velocity shear injuries. With these high velocities, there may be an area of influence around each surface that poses a hazard to fish passage. Based on our judgement and observations during FY97, we assume that within 6 inches of these surfaces may be a high hazard zone for fish. Fish in this area may have a higher likelihood of strike or abrasion injury. If they should change their course slightly, it could take them directly into a hazard area.

The approach to the stay vanes and wicket gates appeared to be a significant factor in determining the likelihood of impacting the stay vane or wicket gate surface. The flow aligned with several stay vanes very well, while at other locations the flow aligned very poorly, causing a rapid change in direction with considerably higher probability of bead impact. Possible future improvements include streamlining or reshaping the stay vane and wicket gate combination, reducing the number of vanes and gates, coating vanes and gates, or constructing them from a different material. Lab tests may indicate whether possible abrasion injuries are flow caused or behavior caused.

As a result of the higher velocities through the stay vane and wicket gate zone and the relatively poor alignment that occurred for a significant portion of the flow, this is considered an area with a high potential for fish injury.

(c) Runner Region

This region covers all areas in the immediate vicinity of the rotating blades. This includes possible strike on the leading edge of the blades; both inside and outside gaps; high velocity passage next to the hub, the blade surface, and the outside ring; and the turbulent region associated with the trailing edge of the turbine blade.

(1) Outside Gap

The outside of the turbine blades spin past the outer ring. The range of the gap between the blades and the outer ring varies as the angle of the blade is changed. In addition, water is passing vertically through the turbine. Pressure changes across the outside gap at the turbine blade are expected to be high. Fish in this area risk being sucked up to the blade, pulled through the gap, or crushed between the blade and the outer ring. It may be difficult to separate injuries caused by this gap from those caused by abrasion along the blades and outer ring. Gaps take up a fairly small part of the outer ring circumference. Therefore, the zone of impact of these gaps may be an important aspect in estimating injury to fish population. Reducing the gap size is currently being studied in turbine design, with a MGR turbine scheduled for installation in 1998 at the Bonneville First Powerhouse.

The outside edge of the turbine blades is an area with a high likelihood of fish injury. Abrasion caused by high velocities in the area, as well as rapid pressure changes at the gaps between the turbine blade and the outer ring, could contribute to fish injury.

(2) Inside Gap at Hub

A gap exists between the turbine blades and the hub of the turbine. The range of the gap changes as the angle of the blades change. Injuries in this area could be caused by pressure changes across the gap, and abrasion as high velocity flows cross the blades and the hub. Injuries due to the gap near the hub should be similar to those seen along the outside gap (with the exception of being crushed between a moving blade and a fixed ring). The MGR design (mentioned above) also reduces the gap in this area.

(3) General Runner Zone

The general runner zone of the turbine is the area in the vicinity of the rotating blades; reference Figure 1. High velocities (up to about 40 fps for turbine flows of 12,400 cfs), pressure changes, and cavitation occur in this area. Fish face risks of injury associated with these plus the possibility of impact with the front edge of the turbine blade and abrasion along the blades, outer ring, or hub.

(4) Trailing Edge of Turbine Blade

The trailing edge of the turbine blade is an area of high shear and pressure changes. Sudden changes in velocity and direction occur as the different pressures from both sides of the blade come together. This is a very difficult zone to analyze using the model due to the rapidly moving parts. Numerical model information may be the best tool for analyzing this region. The actual portion of the flow effected by this phenomenon is relatively small; reference Figure 1. This is a relatively small area with a high probability of injuring fish that pass through it, due primarily to high shear and pressure changes.

(d) Lower Turbine Hub and Draft Tube Elbow

Water exits the turbine with a slight clockwise rotation.. The velocity as it exits the turbine runner area is very high. The flow is then rapidly de-accelerated and turned 90 degrees to align with the draft tube. This creates very turbulent flow with high shear. All fish passing through the turbine would experience these conditions. If shear is a major mechanism for fish injury, this should be considered a major area of concern.

(e) Pier and Draft Tube

After the flow is turned at the elbow, it continues to expand through the draft tube. The pier (located just upstream of the outlet) divides the flow into two paths; reference Figure 1. Impact and abrasion injuries are possible in this area. Turbulence at the pier nose could cause disorientation and additional abrasion injuries from the unsteady flow characteristics.

There appears to be more flow separation at the pier nose in the draft tube at low flows (around 10,500 cfs) than at high flows (around 16,000 cfs). It appears the draft tube design may have been optimized for the higher flow level. Average velocities at the upstream end of the pier range from 12 fps to 18 fps for the above flows (10,500 cfs to 16,000 cfs).   Average velocities at the downstream end of the pier range from 6 fps to 9 fps.

(f) Draft Tube Exit and Backroll

Flow exits the draft tube in a swirl pattern that seems to indicate higher velocities along the bottom of the draft tube than the top. The flow boils to the surface and splits into a front roller that travels quickly downstream and a backroller which generates a vertical eddy against the dam. This backroll of the flow is good habitat for predator fish which could easily feed on disoriented juveniles caught in this portion of the flow. The velocities in this region are low enough that injury from shear is less likely. Predation associated with the backroller may be quite significant. Fish passing through the turbine experience high velocities, rapid pressure changes, high shear, and rapid de-acceleration. Though each of these may not cause direct fish injury, the combination is likely to leave a large number of fish very disoriented and confused state. If half of these fish then pass into the backroller, significant predation losses may occur.

The TSP team, following observations described above, developed a list which identified the priority of study for each zone. Zones were evaluated based upon possible fish injury, fish mortality, and the potential for physical modifications to improve conditions in the area. The following table shows the results of this evaluation and the priority given to various areas for study.

ZONE	POSSIBILITY OF FISH MORTALITY	POSSIBILITY OF FISH INJURY	PRIORITY FOR STUDY	POSSIBILITY OF PHYSICAL MODS
Upstream of stay vanes	No	No	Low	Uncertain
Stay vanes/ wicket gates	Yes	Yes	High	Yes
Outside gap	Yes	Yes	High	Yes
General runner zone	Yes	Yes	Moderate to High	Yes
Trailing edge of blade	Yes	Yes	Moderate	Yes
Lower hub and elbow	Yes	Yes	Moderate	Uncertain
Pier and draft tube	Yes	Yes	Moderate	Uncertain
Draft tube exit and roller	Yes	Yes	High	Uncertain

TABLE 3. Priorities for Zones of Study.
3.3.5 Bonneville Model Test Results

Preliminary fish release locations were determined based on the Bonneville and McNary fish passage models; reference Section 3.3.6.3 for more information on release sites. These sites were chosen to optimize biological information from the MGR.

Prototype testing was originally scheduled for FY98 but, due to delays, is now scheduled for FY99.

3.3.6 Prototype Tests

3.3.6.1 Testing Overview

Hydraulic models will be used to develop and improve McNary prototype tests. It is assumed that beads released in high velocity areas (above 7 fps, capture velocity for 6 inch long juvenile chinook and steelhead) will approximate fish paths through the same areas. Bead flow paths will be studied to determine potential danger zones and "fish" paths through these zones. Release sites will be selected to place fish in the desired areas for prototype testing. Injury and survival information from prototype tests will be used (along with fish distribution information) to estimate the impact potential of each zone on fish injury and survival. Prototype tests were originally scheduled for FY98 but, due to delays, have been postponed until FY99.

Hydraulic models will also be used to develop and improve prototype tests to evaluate changes in fish injury and survival with a MGR at Bonneville Dam 1st Powerhouse. Flow paths through the McNary turbine model will be used to estimate fish paths from the Bonneville scroll case through the turbine (the Bonneville model does not have a turbine). Similar prototype release sites will be used for the minimum gap turbine and a typical turbine to compare fish injury. Fish distribution information will also be analyzed to estimate impact on survival. Prototype tests were originally scheduled for FY98, but have been postponed until FY99.

3.3.6.2 McNary Prototype Test Development

(a) Model Release Sites

Initial release sites were selected based on model information (identification of potential injury areas and flow lines through these areas). Five sites were chosen. Areas targeted for study include the following:

- Minimum impact passage (a route through the turbine that is anticipated to have minimum fish injury).
- Stay vanes and wicket gates.
- Hub gap at turbine.
- Outer gap at turbine.
- Center pier of draft tube outlet.

These sites were selected to provide a better understanding of where injuries are occurring in the turbine passage and what areas would benefit most from modifications. Injuries from the last four passage routes will be compared to injuries from the minimum impact passage to determine biological impacts of potential injury areas.

Release sites will be verified before being finalized for prototype testing. Approximately 500 beads will be released at each initial site and their paths studied to evaluate if the site will provide adequate biological information. Information from studying bead paths may also roughly indicate what portion of fish may be injured from each release site. New release sites will be selected if necessary.

(b) Prototype Release Sites

In an attempt to confirm that bead paths in the model can represent fish paths in the prototype, verification studies will also be conducted (reference Section 3.1). Currently, technology to track fish to the wicket gate area is being researched. It is important to confirm the fish path through the turbine passage for two reasons: (1) If fish paths are confirmed, the strength of the biological tests results increase, and (2) A higher confidence in the use of hydraulic models to evaluate fish passage conditions and possible improvements would provided.

3.3.6.3 Bonneville Prototype Test Development

Initial release sites were selected based on model information. The following three sites are targeted for study:

(1) MIP (a route through the turbine that is anticipated to have minimum fish injury).
(2) Hub gap at turbine.
(3) Outer gap at turbine.

These sites were selected specifically to evaluate potential benefits of a MGR turbine design.

SECTION 4

RELATED ACTIVITIES

4.1 DOE SHEAR PROGRAM

The U.S. DOE's AHTS has been funded by Congress to support the research and development of "environmentally friendly" turbines, i.e. turbine systems where environmental aspects of the turbine design are emphasized. These aspects include and address a number of environmental concerns (low dissolved oxygen downstream from projects, minimum in-stream flow requirements, pollution from hydro-machinery lubricants, etc.), but also emphasize improving the survival rates of fish that are entrained and must pass through the turbine environment.   The goal of the AHTS is to develop advanced turbine designs that would improve the survival rates for fish passing the turbine environment, by utilizing the latest technologies and passage and design information. Newly designed turbines could be suitable for replacing aging turbines at existing plants. It is envisioned that these new designs would minimize the damage to fish while maintaining a high level of generation efficiency.

The DOE AHTS program has been developed, reviewed, and coordinated with utility industry and federal government agency representatives through the use of a Technical Review Team.   This review team is comprised of federal and private engineers and biologists who meet regularly to provide direction and oversight to the AHTS program for the DOE. The Corps of Engineers is represented on the AHTS review team by a senior mechanical engineer from the HDC (Paul Willis), a senior biologist from the WES (Tom Carlson), and a fish passage biologist from Portland District COE (John Ferguson).   The Corps' active participation in the AHTS review team allows technical information to flow between the DOE AHTS and the COE TSP, thereby reducing costs and program overlap.

The DOE AHTS program has been developed along two pathways. First, the conceptual development of a totally new and promising design of a turbine that meets the environmental requirements established by the DOE; second, the development of turbine design specifications from the existing biological data base or from additional studies that design engineers can then use to develop updated turbine designs for existing hydro-machinery. The shear work funded by the DOE is a part of the second program pathway.

In 1995, the COE convened a panel of engineering and biological experts to discuss and prioritize the potential mechanisms of injury associated with fish passage through turbines (Wittinger et al., 1995). Shear was rated second only to mechanical injury as a mechanism that needed additional study in the direct injury category.   Noted was the importance of quantifying a fish's ability to withstand shear and turbulence.   Turbine manufacturers could then use the knowledge gained in this area to design the turbine environment to maintain shear levels below those thought to produce levels of injury or mortality.   The COE considered incorporating shear studies as part of their investigations

through the TSP. However, since DOE was planning to investigate this aspect of turbine design through the AHTS, the COE did not include it as part of the TSP.

DOE has assigned technical leadership, oversight, and responsibilities of the shear program to Oak Ridge National Laboratories (ORNL). ORNL reviewed the existing information on turbine passage injury mechanisms (Cada, et al., 1997), and suggested that shear, among other mechanisms, be considered as an important biological design criteria that should be considered in the design of new turbines.   ORNL spent the better part of FY97 reviewing existing shear and turbulence information, literature, and laboratory techniques used to date.   ORNL concluded that shear and turbulence are both expressions of changes in water velocity. Understanding shear and how it is best described and measured were important discussion requirements for the DOE AHTS effort that needed to be defined prior to a initiating any shear research.   ORNL spent a great deal of time in 1997 framing up the shear issues for DOE and the AHTS Technical Review Team. This work is summarized in Cada (1997). Based on this summary, ORNL describes the important shear components and information as follows:

Velocity (v) is measured in distance (y) per unit time, e.g., m/s. Shear occurs when two water masses of different velocities intersect or are adjacent to each other. Shear is defined as the change in water velocity (v) over distance (y), expressed as m/s per m, or units/s :

$$shear = dv/dy$$

If there was no resistance to flow (no viscosity), the fish would spin freely in response to the different velocities impinging on it and would not experience any harm (other than disorientation due to spinning).   However, because the water is which the fish is traveling has viscosity, force is exerted on the fish as a result of encountering a mass of water moving at a different velocity. Depending on its magnitude, this force may be harmful. Therefore, shear is not a sufficient measure of potential expression of potential damage to fish, and that estimates of shear must be combined with estimates of viscosity to obtain shear stress.

Force is defined as mass multiplied by acceleration and is expressed in Newtons (N). The effect of force is governed by size of the fish (large fish have more mass and would strike a structure with more force for example), life stage (sensitivity), the way a fish strikes a structure (head first vs. side of the body). Pressure is force per unit area, applied perpendicular to the body surface, expressed in N/m^2.   If all the force (fish's mass multiplied by acceleration) of striking a structure is focused on one small point, there will be greater pressure and injury than if the entire side of a fish's body strikes a structure, wall, or another water mass of different velocity.

Shear stress, like pressure, is force per unit area. The difference between pressure and shear stress is the direction in which the force is applied. Pressure forces act perpendicular to the surface, whereas a shear force acts parallel to it. Shear stress is also expressed as

pressure, in N/m^2. A fish can experience shear stresses when passing between two water masses of different velocities or along a fixed structure (turbine blade, stay vanes, wicket gates, wall, etc.). As with pressure, a given amount of shear stress focused in a small area is expected to cause more damage.

Turbulent flow occurs when fluid particles move in a highly irregular manner, rather than the fluid as a whole moving in one direction.   Turbulence can only be defined statistically, and it exists in all scales in nature. Flow past fixed structures can cause chaotic or turbulent flow fields, that could lead to turbulence caused disorientation that may leave a fish more susceptible to predators in the tailrace.   Shear stress can also be estimated for turbulent flows, but the equations are more complicated because a term for eddy viscosity has to be incorporated. Turbulence can also be described by a measure called turbulence intensity. For example, local velocity in a turbulent region can be described as a mean and a fluctuation about the mean.

Given these definitions and expression of shear and turbulence, ORNL began to look at sites and laboratories that would be able to conduct shear experiments. ORNL recommended and DOE accepted Battelle Pacific Northwest Laboratories (PNNL) in Richland, WA to conduct the shear and turbulence experiments. Duane Neitzel was selected as the PNNL study manager, and PNNL developed a team to support the DOE effort. From May 1, 1997 through September 30, 1997, PNNL developed a biological study plan titled: Biological Studies to Determine the Effects of Shear and Turbulence Stresses on Turbine-Passed Fish. PNNL proposed to conduct controlled experiments at the PNNL facilities on the Hanford Nuclear Reservation (PNNL, 1997). The proposed biological work will be coupled with physical modeling to relate test conditions to levels of shear and turbulence stresses a fish might encounter in a mainstem Kaplan turbine environment. The fish's behavior while passing through the turbine may alter the passage route, leading to greater or lesser exposure to these injury mechanisms.   Because fish behavior in a turbine cannot be reproduced in the laboratory apparatus, physical modeling which incorporates existing knowledge of fish behavior and new data on variable stress exposure histories is needed to extend the experimental results to advanced turbine designs.

PNNL proposed a phased approach for conducting the tests needed to develop biological design criteria for shear and turbulence. Phase I, conducted in 1997, involved the following tasks:

1. Define and estimate (quantify) shear and turbulence levels in existing and advanced turbines:

- maximum shear/turbulence
- average shear/turbulence
- minimum shear/turbulence
- exposure times
- representative shear-time and turbulence-time exposure histories

2. Define and prioritize the biological components of the shear and turbulence tests:

- test species
- fish size
- fish orientation
- fish constraints during testing (free swimming, anesthetized, etc.)
- biological response(s) to tests (mortality, injury, indirect effects)
- statistical definition and precision of results
- range in independent variables (i.e. shear and turbulence)

3. Design a laboratory apparatus that can reproduce these quantities in a controlled and reproducible manner.

4. Set up an interim facility to conduct range finding tests with juvenile salmonids.

Phase II will be conducted in 1998, and will include the construction of the test facility, conducting the tests, and quantifying the biological responses.

The PNNL proposal was sent to the DOE AHTS Technical Review Team for comment. Due to the complex nature of the subject (shear and turbulence), the review team discussed the pertinent issues. These included how to measure shear, how to express shear, how to test for shear effects, and how to report biological consequences and significance. Based on the level of discussion and difficulty in understanding the subject, DOE asked that the Technical Review Team form a subcommittee to address the shear work. The subcommittee met at PNNL offices in Richland, WA on April 28, 1997. The subcommittee discussed and provided input on the limitations of studies that had been conducted previously by others, experimental techniques, experimental protocols, and conditions for the DOE studies. On August 20, 1997, PNNL provided DOE and the technical review subcommittee with results from computer code model simulations to predict flow field and shear stress distributions from various source velocities to support the design of an experimental test facility. The modeling exercise concluded that the proposed experimental test flume could provide the desired range of velocity and shear stress.

In summary, DOE and ORNL have made a great deal of progress in FY97 toward reviewing past studies and developing a program to investigate stress and turbulence. PNNL was contracted and made considerable progress toward developing a detailed study design, and investigating research facility logistics and flume simulations to ensure the physical requirements of the test can be met at PNNL facilities. Review of the program by a subcommittee of the DOE AHTS Technical Review Team is ongoing, and provides input to PNNL, ORNL, and DOE on the scale, type, and statistical measures that must be considered for the products from this program to be useful and effective. Based on the Phase I work conducted by PNNL in FY97 and the Technical Review Team subcommittee

review comments, DOE is proceeding with the shear work in FY98. Further technical review subcommittee meetings will be held to focus the PNNL effort.

The Corps' will continue to participate in the DOE AHTS Technical Review Team to provide technical input and reduce program overlap. The Corps will input the results of the DOE AHTS into the TSP reports as products and findings are produced.

4.2   TURBINE WORKING GROUP

Throughout the region and nation there are various efforts underway by different groups which are investigating the turbine environment for specific reasons. Many of these efforts are related to improving fish passage through turbines. To assure that duplication is not taking place, as well as to coordinate efforts and funding of activities, the TWG was formed. This group provided information, coordination, advice and guidance to the evolving efforts to improve fish passage through Kaplan turbines. The group is composed of various COE entities, DOE entities, several PUDs, the NMFS and the EPRI. Voluntary monthly gatherings, held since 1994, provide advice and guidance on developing and coordinating a program to provide survival enhancement of fish passing through a turbine water passage and determine the mechanisms which effect them.

During FY97, the TWG provided guidance, advice and support to on-going and planned investigations. At the recommendation of the TWG, an investigation (beginning in FY96 and completed in FY97) of a suitable site on the Columbia and/or Snake Rivers for engineering and biological evaluation of a Kaplan turbine was undertaken and resulted in the Base Case report entitled "Turbine Passage Survival Baseline Turbine Report." This base case report and subsequent recommendation by the TWG to use McNary Unit 5 as a regional test turbine for baseline prototype testing was accepted by the Corps and Region. The TWG provided coordination, review, comments and advice in the development of the COE TSP. Various members of the TWG volunteered to coordinate, investigate and document investigations into possible juvenile fish mortality mechanisms recommended for study in the "1995 Turbine Fish Survival Workshop Proceeding" (sponsored by the Corps and TWG). These investigations include the following:

- In FY97, the DOE, through the AHTS, investigated existing known biological design criteria and supported CFD numerical developments. The DOE chose to investigate shear and turbulence as a fish passage mortality mechanism in FY98, as well as to technically assist in other investigations.

- In FY97, the EPRI volunteered to initiate investigations in FY98 into the possible mortality mechanism of pressure, as well as to technically assist in other investigations.

- Grant County PUD volunteered to investigate imaging techniques for use within a turbine water passage in FY97 and FY98.

- The BPA volunteered to take the lead in investigating and developing an outline and study plan to examine the existing 1% turbine efficiency operating limit. The purpose of this study plan is to better identify the optimum turbine operating conditions for maximum safe juvenile fish passage through existing turbines. The TWG provided initial guidance, advice, technical assistance and development of an overall outline to assist BPA in the development of the study plan for submission to the NMFS and the region.

- The TWG provided coordination, guidance and recommendations on the use of the McNary WES hydraulic model as a tool to investigate the turbine water passage. In addition, the TWG provided partial funding and technical support for the production of regional videos for public release to explain the turbine fish passage route and the efforts being made by the region to improve juvenile fish mortality through all passage routes at existing dams. Final release of the videos is expected in FY98.

4.3 TURBINE OPERATION BEYOND 1%

A 1% efficiency limit on the turbine best operating point is in the NMFS 1995 Biological Opinion and in the COE Fish Plan, which is the basis for how the COE operates to enhance fish passage and protection at COE dams. The hypothesis that Kaplan turbines operated at higher wicket gate and blade settings may provide improved juvenile fish survival conditions within the turbine environment was proposed at the turbine symposium. It has been suggested that the original designs of existing Kaplan turbines were optimized near full load conditions and the efficiency loss charged to the turbine at these conditions include a major component due to hydraulic frictional losses not associated with Kaplan turbine runner performance. Turbine operation at increased spacing of movable turbine mechanical components (runner blades and wicket gates) may reduce the probability of mechanical injury to fish due to strike. Verification of this hypothesis would greatly increase system operational flexibility, reduce involuntary spill, gas production and possibly reduce gas related impacts to fish stocks. Several meetings initiated by the TWG have been held to discuss operating beyond the 1% limit. These meetings have resulted in a consensus that such investigations should be conducted in an attempt to optimize juvenile fish passage through Kaplan turbines. The BPA volunteered to pursue development of a draft study plan to investigate the issue with the assistance of the TWG.

During FY97, the TWG, with BPA and NMFS assistance, developed a general proposal outline. BPA continued work in FY97 to develop a draft report which details the process, procedures and methods proposed to investigate and prove or disprove the hypothesis. BPA has projected completion of the draft study plan in FY98.

4.4 LOWER GRANITE DRAWDOWN AND SBC TURBINE STUDIES

4.4.1 Drawdown Turbine Studies

4.4.1.1 Background

The Walla Walla District is investigating the feasibility of a "Natural River Drawdown" for the four lower Snake River dams. The basic idea behind the Natural River Drawdown is to breach the earth-fill section of each dam so the dams no longer impound water in the reservoirs, providing free-flowing conditions along the entire reach of the lower Snake River. Before the earth-fill embankments are breached, the reservoirs must be drafted as low as possible.

The spillways can be used to lower the reservoir water surfaces to near the spillway crest elevation at each dam. Below the spillway crest, there are no low-level outlets other than the turbine passages through the powerhouse. The four lower Snake River dams were designed as run-of-river projects, meaning the turbines were designed to operate over a narrow range of forebay water surface elevation, typically only three to five feet difference between minimum and maximum operating pool. A report entitled *Lower Granite Dam, Turbine Passage Evaluation*, prepared in 1996 by Raytheon Infrastructure Services Incorporated, indicated that it may be feasible to use the turbine passages to draft the reservoirs far below normal operating range. However, the report recommended further studies to evaluate the issues involved in such an action.

The COE worked with a contractor to evaluate intermediate- and low-head turbine operation using an existing 1:25 scale turbine model for a Lower Granite Lock and Dam (Lower Granite) turbine. At the same time, WES conducted tests using a bladeless runner in the Lower Granite 1:25 scale sectional turbine model. HDC provided assistance in interpreting the model test data and suggesting actions necessary to prepare for a reservoir drawdown using the turbine passages to draft the reservoir. Several modifications will be necessary to allow safe operation at the intermediate- and low-head conditions associated with a reservoir drawdown while still providing for the required discharge capacity.

4.4.1.2 Hydraulic Turbine Model Testing

Hydraulic turbine model testing was performed using a 1:25 scale model of the Unit 4 turbine at Lower Granite, to predict turbine operating limits and conditions under anticipated drawdown conditions. These conditions consisted of turbine operation at and below the existing spillway crest elevation of 681.00 fmsl and tailwater elevations of 633.00 feet mean sea level (fmsl) and 624.00 fmsl. The turbine model operated over head ranges of 48.00 ft to 8 ft for the tailwater of 633.00 fmsl and 57 feet to 17 feet for the tailwater of 624.00 fmsl. The testing investigated four wicket gate openings (100%, 75%, 50% and 25%) and two runner blade angles (minimum opening of 20 degrees and maximum opening of 32 degrees). In all, approximately 160 test conditions were performed. The lower bound for the testing was established as the point where the prototype turbine produces no electrical power, which is referred to as "speed no load" (SNL). All testing was conducted without ESBS's in place.

The model test results, brought to prototype conditions through hydraulic affinity laws, indicate the following limits of prototype drawdown operation. These are general results, subject to some limitations, that should provide acceptably safe operating conditions:

- Pool elevation range from 681 fmsl to 644.2 fmsl
- Gross head range from 57 ft to 20.2 ft
- Flow range from 20,750 cfs to 7,700 cfs
- Wicket gate operating range of 100 percent to 38 percent, depending on the specific site hydraulic conditions.

In addition to measured data, qualitative information was obtained through direct observation, to identify effects on stability of operation. These observations indicated that a vortex was formed on the runner for some conditions. The vortex is an indication of undesirable and possibly unsafe zones of turbine operation. Development of a vortex normally corresponds with severe unstable conditions. The vortex forming and collapsing creates pressure pulsations and causes severe vibrations from unstable flow distribution to the runner. Observations indicated that the worst conditions of unstable operation and vortex formation occurred with a blade angle of 32 degrees, wicket gate openings from 100 percent to 75 percent, and heads of 46 feet and below. The worst condition noted during the observational testing was for 100 percent wicket gate opening, 32 degrees blade angle, tailwater of 624 fmsl, and gross head of 28.2 feet (SNL condition).   As head on the turbine is reduced with a blade angle of 20 degrees (for either tailwater), the model testing indicates acceptable to marginal operating conditions.

Modeling techniques did not allow investigation of cavitation phenomena. However, it can be expected that significant cavitation will occur, increasing the tendencies for unstable operation at high flows and low tailwater conditions. Severe cavitation could also cause damage to the machinery and structures.

4.4.1.3 WES Model Testing

WES performed hydraulic turbine model testing using a 1:25 scale sectional turbine model for Lower Granite, with a bladeless runner installed. Numerous experiments were performed at a tailwater of 624.0 fmsl to determine the capacity of the turbine unit at various forebay pool elevations and to give some indication of turbine operating conditions. Both velocity and pressure data were collected. Curves were developed to help determine how to operate the unit to achieve the desired drawdown rates. These curves are straightforward and were repeatable.

A total of ten velocity experiments were performed to document what flow conditions might exist at various operation points that might occur during the drawdown process. Velocities were measured in the intake structure upstream of the wicket gates in Bays A and B, in the vicinity of the bladeless runner, and in both barrels of the draft tube.

The velocity experiments indicated that no problems would be anticipated for flow conditions upstream of the wicket gates. This is true for all heads and discharges, as long

as the trash racks and wicket gates are free of debris. As the reservoir is drawn down, debris loading may increase. Velocities and flow conditions in the turbine intakes will be affected if debris accumulates on the trash racks.

Measured velocities four feet upstream of the upstream edge of the wicket gate varied between 13.2 ft/sec for a turbine loading of 20,000 cfs to 5 ft/sec for a discharge of 7,000 cfs. The flow is accelerating and can be expected to reach magnitudes of 50.7 ft/sec for a turbine loading of 20,000 cfs to 14.8 ft/sec for a turbine loading of 7,000 cfs and an upper pool of 640.0 ft at the controlling point of the wicket gate opening. These velocities just downstream of the wicket gates are higher than would be expected with a bladed runner, although high velocities would be expected in this area with a bladed runner. The measured velocities upstream of the wicket gates indicated no instabilities in the approaching flow field.

Velocities measured in the vicinity of the runner indicated high velocities could be expected in this area for discharges of 20,000 cfs and 15,000 cfs. Measured velocities for a turbine loading of 20,000 cfs were as high 93.4 ft/sec near the runner, much higher than expected. At this measurement section, the average velocity based on the available area would be approximately 46 ft/sec. Measured velocities for lower discharges were as high as 57 ft/sec.

Unstable flow conditions, due to cavitation and severe turbulence, are likely to occur when there are extremely high velocities. Large vibrations occurred in the model for discharges of 20,000 cfs. While these vibrations are not scaleable, it is an indication of poor operating conditions for the unit in the prototype, even for short durations.

Velocities measured in the draft tube indicated a very non-uniform flow field. This was true for all ten experimental conditions. These conditions should not prohibit the use of the bladeless runner for the natural river drawdown process. However, for all ten conditions, the boil that occurs downstream in the tailrace area occurred much further downstream than was expected. The boil in the independent contractor's bladed runner model occurred much closer to the structure than it did in the WES model. The bladed runner removes much of the energy in the flow to produce power with the generator. With a bladeless runner, most of this energy remains in the flow, so the boil occurs much further downstream. This may have an effect on scour in the tailrace area downstream of the draft tube exits, depending on how well the bed is armored.

Pressures were measured at five locations in the vicinity of the bladeless runner. Four of these locations were on the discharge ring and one was located on the bladeless runner itself. These experiments indicated that cavitation occurred on the bladeless runner for discharges of 20,000 cfs. These pressure readings are consistent with the extremely high velocity measurements noted for these discharges. Tests also indicated that there is potential for cavitation on the runner for discharges of 15,600 cfs and 15,000 cfs. The cavitation associated with the 15,000 cfs range is probably not of the magnitude to

prohibit operating the bladeless unit for the length of time it would take to draft the reservoir down to elevation 640 fmsl.

4.5 McNARY UNIT 5 CAM VERIFICATION FIELD PERFORMANCE TESTING

The McNary cam verification field test for Unit 5 is scheduled for fiscal year 1998. The procurement work completed in FY97 consisted of selection and acquisition of field test equipment. The equipment, which is to be a semi-permanent installation, consists of the computer and data acquisition system, transducers and consumables for installation at the site. The engineering work completed consisted of development of a field testing brochure, contract preparation and procurement activities related to the use of the flow scintillation measurement technique at McNary and Bonneville. The initial development of the McNary cam verification data for the Froude and Reynolds model testing and 1993 field testing, as well as coordination both within the Corps of Engineers and with the Region to arrange testing schedules and activities, was also completed.

4.6 MODEL TURBINE PERFORMANCE TESTING

There is no specific turbine performance modeling proposed under the approved PSP. Previously contracted turbine modeling work for McNary Unit 5, Bonneville Powerhouse Rehabilitation model testing of the base case, MGR and surface bypass collector effects, Dardanelle Powerhouse Rehabilitation model testing, Lower Granite Unit 4, CFD analysis of Sault Ste. Marie Unit 3A and modeling work performed by other agencies have been or are being performed. The purpose of most of the modeling efforts is to identify effects of design changes on turbine performance.   Specifically for the McNary effort, different modeling techniques and the effects of fish diversion devices are being investigated to determine which best represents prototype turbine performance with fish screens installed in the intakes. Turbine performance modeling is to be used to identify the predicted prototype performance response and has been selected over comprehensive prototype field testing because of cost, accuracy and flexibility. The focus of these models is to determine power and turbine performance issues. Curves and turbine settings related to turbine performance were developed using these models. Since the model is made of steel, limited visual access is available.

SECTION 5

FY98 AND BEYOND ACTIVITIES

5.1 BIOLOGICAL STUDIES

In FY97, the biological studies portion of the TSP was limited to study design, planning and purchasing of equipment. Details of the biological activities planned for FY98 and FY99 are included in Section 3.1.

5.2 ENGINEERING STUDIES

5.2.1 Operational Optimization

The operational optimization of McNary Unit 5 consists of performing turbine index testing to identify operating conditions that are consistent with the design and present operating parameters. This testing will assure that the turbine(s) are operating as efficiently as possible prior to actual biological testing. This field index testing is to be performed with and without fish diversion devices in place and is scheduled to occur in FY98.

In order to perform field testing in a reasonable time frame and to monitor turbine operation during biological testing, long term installation of instrumentation and data acquisition equipment is required at McNary. Most of this equipment was purchased and installed in FY97, with the remainder of the installation occurring in FY98; reference Section 3.2.2 for details on the instrumentation.

The "on cam" curves developed from a 1993 Index test, the Froude model test and the Reynolds model test for conditions with and without fish screens installed will be tested in the FY98 field test at McNary Unit 5.

5.2.2 Turbine Environment Studies

The purpose of these studies is to better define, in engineering terms, existing conditions within the turbine water passage environment. Two areas to be investigated under the TSP include turbine environmental imaging and pressure distribution. This program is also being coordinated with ongoing WES hydraulic model studies throughout the length of the project.

Imaging information will be obtained from the Grant County PUD following completion of their work on the Wanapum Kaplan turbine; current status is unknown. EPRI tentatively agreed to investigate water passage pressure distributions, with work expected to continue into FY98. In addition, pressure will be measured in the McNary Unit 5 field test scheduled for FY98. Reference Section 3.2.3 for additional details.

5.3 HYDRAULIC MODELING

5.3.1 1998 Model Tests

5.3.1.1 McNary Dam Model

Tests scheduled for FY98 include verification of fish release locations, completion of flow line mapping, and study of conditions when operating outside of within 1% of peak efficiency.

Verification of fish release locations has two aspects. First, preliminary release sites need to be statistically evaluated insure these sites adequately impact the identified zones of concern for fish passage. This will be done in the fish passage model. Reference section 3.3.6.2(a) for more information on verification tests. Second, the release sites to need to be tied to vertical fish distribution through the turbine passage, in order to evaluate the impact of zones of concern on overall fish injury and survival.

Flow line mapping was completed through the stay vanes and wicket gates (with and without ESBS's) in FY97. The remainder of the flow line mapping (from the turbine through the backroll in the tailrace) is to be completed in FY98.

Other model tests will focus on conditions through the turbine passage when operating turbines outside of within 1% of peak efficiency. Currently, turbines are operated within 1% of peak efficiency (when possible) to provide improved fish passage conditions. Operation of turbines at higher flows could provide better fish passage conditions if the additional losses are due to friction along the intake and draft tube walls rather than turbine inefficiency. If the blades and wicket gates are more open, there should be less chance for impact injuries during fish passage. Additional efficiency losses due to friction along the intake and draft tube walls may have minimal impact on overall fish injury and survival.

5.3.1.2 Bonneville Dam Model

Tests to verify fish release locations for biological tests are scheduled for 1998. These verification tests include statistically evaluating preliminary release sites (in the fish passage model) and tying sites to vertical fish distribution (through the computer model); reference Section 5.3.1.

5.3.2 Future Hydraulic Tests

5.3.2.1 McNary Dam Model

Several areas are anticipated for future testing on the McNary Turbine Intake 1:25 Sectional Model:

(a) Zone through turbine area. This may three dimensional laser readings, pressure measurements, etc.). In order to improve turbine design, conditions in this area need to be better understood.
(b) Operational improvements. Changes in operation with existing equipment (turbines, wicket gates, etc.) will be studied to determine if there are possible benefits to fish passage. Examples of possible improvements include changing turbine flows, turbine blade settings, and wicket gate settings.
(c) Three dimensional laser readings. Three dimensional laser readings will be taken to get an idea on conditions in and near the turbine environment. Readings may also be used to calibrate a numerical model.
(d) Pressure information. Pressure readings are scheduled to be taken in the hydraulic model. These should give an indication of pressures in the prototype for equipment placement and fish condition and serve as a cross check for numerical model information.
(e) Physical improvements. Physical improvements will be explored to see if changes to turbines, stay vanes, wicket gates, or the draft tube could benefit fish passage. Possible improvements include changes to streamline stay vanes and wicket gates (to minimize strikes), turbine blade improvements (to minimize strikes and gaps), and draft tube improvements (to minimize turbulence in the draft tube and in the outlet backroll).

SECTION 6

SUMMARY/CONCLUSIONS

FY97 efforts on the TSP have produced the following conclusions or recommendations:

(1) Appropriately scaled physical hydraulic models can be used to observe and characterize the hydraulic conditions present within Columbia River Kaplan turbines that juvenile migrating salmonids are potentially exposed to. Neutrally buoyant beads can be used to trace stream tubes within the model turbine, and high-speed digital photography can be used to record the bead behavior and pathways. Dye tracings can be used to define how flows distribute around the stay vanes/distributor per a given release point. Bead and dye distribution is dependent on point of release.

(2) Based on our hydraulic model studies, we conclude that results from some previous biological studies of turbine mortality may be biased. This is based on the observation that the locations that beads and dye pass through wicket gates and enter the turbine environment is very dependent on point of release in the intake. We have also observed that the injury potential for fish is may be strongly dependent on its path of passage through a turbine. In many of the more recent turbine mortality tests, fish were released at specific point(s) in a Kaplan turbine intake. We conclude, based on our observations of bead and dye movement patterns through the McNary turbine physical model, that these release strategies likely do not result in a random distribution of through turbine passage paths. Therefore, it is likely that the results of these tests are specific to the release points and are not an unbiased measure of total turbine survival. This concern would not apply to some of the older fish survival data sets where test fish were not released from specific in-turbine intake locations. For example, in some studies fish were released in the forebay upstream from turbine intakes. Such release strategies probably resulted in a more random distribution of fish turbine passage paths and are more likely to have provided an estimate of total turbine mortality unbiased by through turbine passage path concerns. Additional physical model and prototype studies will be required to verify whether these concerns are justified.

(3) Passive and active hydroacoustic methods will be used to estimate fish distribution within turbine intakes downstream of control gate slots. Initial emphasis will focus on evaluation of the use of fish distribution information from fyke net and hydroacoustic FGE sampling conducted upstream of control gate slots as a basis for estimating fish distribution further downstream in intakes. Sampling tools developed during phase I of the TSP will permit measurement of fish distribution at locations well downstream of control gate slots if necessary.

(4) Observations of the trajectories of passive objects and fish during passage through the downstream half of turbine intakes will be compared with observation of the

trajectories of neutrally buoyant beads in the McNary 1:25 turbine physical model. These comparisons will be used to test the validity of using physical model observations of bead movements as estimates for fish movements during turbine passage and to provide a data base for calibration of the physical model for this use if it proves necessary.

(5) Visualization of hydraulic flow conditions within a Kaplan turbine achieved by using the 1:25 scale McNary physical model has been very productive. Qualitative and quantitative observations have clarified relationships between turbine flow dynamics and potential for fish injury. The observations have permitted identification of zones of potential injury and are also providing data necessary to identify specific potential injury mechanisms within these zones that may be modified through operational or structural means. Work products to date validate the conceptual base described in the PSP. It appears very likely that completion of the TSP Phase I will deliver an understanding of the turbine environment and fish injury during turbine passage that will result in identification of turbine operation and structural changes to significantly improve the safety of fish passage through turbines.

(6) In FY97, a substantial amount of time was spent observing hydraulic flow conditions in the 1:25 McNary sectional intake and turbine model. We conclude that the conceptual framework for the TSP that was developed in the PSP is intact. These FY97 activities confirmed that our knowledge and understanding of potential operational improvements and design changes to mainstem Columbia River Kaplan turbines can be substantially improved through the execution of Phase I of the TSP. Because of the information gained in FY97, we conclude that TSP efforts should continue as planned into FY98 and FY99.

(7) Based on observations of draft tube swirl in the McNary 1:25 sectional model, the TSP team is considering recommendation of the addition of another biological study to the TSP. By using fish tagged with Passive Integrated Transponder (PIT) Tags, the potential effects of disorientation caused by the swirl can be evaluated, along with any effects from turbine passage that are manifested downstream of the turbine environment. Discussions of this addition will occur with regional interests in 1998.

SECTION 7

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SECTION 8

APPENDICES

APPENDIX A : DATA COLLECTION TECHNIQUES

Several methods were used to collect data in the turbine model. They include the following:

(1) Neutrally buoyant beads. These were used to map flow lines and determine bead distribution through the stay vanes and wicket gates. Beads were released downstream of the intake gate slot to get past flow disturbances caused by the ESBS's, as well as to develop a better understanding of how ESBS's affect flow distribution through the turbine environment. Beads seemed to provide a better indication than dye of potential trouble or injury areas for fish. Using beads, it was easier to see "dead" spots in the flow than with dye. In addition, bead strikes on stay vanes and other objects provided an indication of possible fish "strike" areas and helped determine release points for biological testing.

Two types of beads were used for testing in the model. Polifil GFPPCC beads, manufactured by Plastics Group of America, were used in the intake. They have a specific gravity of 0.98. Huntsman PS316 beads, manufactured by Huntsman Inc., were used in the turbine environment. These beads have a specific gravity of 1.04.

During the development phase of the program, at least 15 types of materials were tested for use in the model. The above two provided the best performance. Polifil beads were soaked in a vat of water for several days. A small percentage of the beads sank. These beads have the closest density to water. We also tried coating these beads with materials to change the density. Due to difficulty controlling the density of the output particle, this approach was abandoned.

Because of the low velocities in the intake, it was important to have beads as close to neutrally buoyant as possible. Beads that sink or float would skew results. Higher velocities through the turbine environment allow the use of beads that are not quite neutrally buoyant. With the higher velocities, the slightly heavier beads did not have a chance to sink.

(2) Dye tracings. Potassium permanganate was used mainly to confirm bead path flow lines and was used from the entrance to the intake gate slot to study flow lines in this area.

(3) High speed video. Video was used to capture beads passing through the turbine passage area. This provided information on bead paths through the wicket gates, strikes on various components of the turbine passage (such as the stay vanes, wicket gates, and turbine), and bead paths through the turbine itself. A Locam II Series 51 camera was used. It is manufactured by Redlake Locam High Speed Instrumentation. Recording at 120 frames per second and playing the video back at normal speed simulated prototype passage speed but was too slow to provide much clarity. Recording at 700 to 1000 frames per second offered much greater clarity.

While recording at higher speeds offered a clearer picture of bead paths, it required greater coordination to capture the beads on film. Approximately ten beads were released at a time, which pass through the turbine passage fairly quickly. While recording at 1000 frames per second, a typical hour long tape covers about four minutes of real time. Most

video was recorded at 500 to 1000 frames per second in the turbine environment. In order to determine the third dimension of beads passing through the turbine, two cameras were used to film at different angles at the same time. Film was "tagged" so it could be synchronized and the third dimension of bead travel could be determined.

(4) Digital high speed photography. The Imacon 468, manufactured by Hadland Photonics Inc., can shoot at speeds up to 100,000,000 frames per second and can clearly show images of beads passing through the turbine blades. Photos were used to provide stop action images of the stay vanes, wicket gates, and turbine area. Software (Imacon 468 software supplied with the camera) is available to provide velocity information from these photos.

(5) Two dimensional laser. Lasers were used to take velocity measurements in the model. This information was used to verify data from the model with the independent contractor data and with previous WES tests in the 1:25 McNary model. Two dimensional laser readings were also used within areas of the turbine where the three dimensional laser couldn't reach. Two dimensional laser readings were quick to take and were useful in many situations.

The laser doppler velocemetry system consists of the following:

- A 4-watt Inova argon-ion laser.
- TSI, Inc. optics for 2-color 4-beam system.
- An 83 mm fiber optic probe.
- Velmex computer controlled traversing system.
- TSI IFA 650 signal processors.
- TSI data acquisition software.

The laser is manufactured by Inova, Inc.. The laser doppler velocemetry equipment is manufactured by TSI, Inc..

(6) Three dimensional laser. This system will be used in 1998. The laser can take a three dimensional velocity measurement at any point. It is planned for use in the blade area and near the wicket gates to provide an idea of conditions here. While this method provides good information, it requires extensive set up and calibration time (up to two days per reading).

The laser doppler velocemetry system consists of the following:

- A 4-watt Inova argon-ion laser.
- TSI, Inc. optics for 3-color 5-beam system.
- An 83 mm fiber optic probe.
- A Velmex computer controlled traversing system.
- TSI IFA 650 signal processors.
- TSI data acquisition software.

The laser is manufactured by Inova, Inc.. The laser doppler velocemetry equipment is manufactured by TSI, Inc..

(7) Three dimensional computer graphic layout of the turbine intake. This was drawn into AutoCAD. Flow lines and bead information were entered onto this layout to provide a visual, three dimensional representation of flow line data.

(8) Pressure readings. These will be obtained near the perimeter of the model. While pressure readings will be used to double check the prototype, they have not been used on the McNary model at this time.

APPENDIX B: McNARY TURBINE MODEL FLOW LINE MAPS, BOTH WITH AND WITHOUT EXTENDED LENGTH SUBMERGED BAR SCREENS (ESBS's)